9950 - 751

APPLIED CONCEPTS CORPORATION

(NASA-CR-169901) THERMAL SYSTEM ENGINEERING EXPERIMENT Final Report (Applied Concepts Corp.) 69 p HC A04/MF A01 CSCL 10B

N83-19215

Unclas
G3/44 02825

THERMAL SYSTEM ENGINEERING EXPERIMENT

FINAL REPORT

Document No. K05-01-82 FR

October 29, 1982

JPL Contract No. 955926

DRD Item No. 11, DRD Reference No. TE 08

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared by:
APPLIED CONCEPTS CORPORATION
109K North Main Street
Woodstock, Virginia 22664

THERMAL SYSTEM ENGINEERING EXPERIMENT

FINAL REPORT

Document No. K05-01-82 FR

October 29, 1982

JPL Contract No. 955926

DRD Item No. 11, DRD Reference No. TE 08

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared by:
APPLIED CONCEPTS CORPORATION
109K North Main Street
Woodstock, Virginia 22664

APPLIED CONCEPTS CORPORATION

ORIGINAL PAGE IS OF POOR QUALITY

Photograph of Capitol Concrete Plant

Abstract and Summary

From December 30, 1980, to May 31, 1982, a "Thermal System Engineering Experiment" was conducted to determine the technical feasibility of using the Power Kinetics, Inc. (PKI) solar thermal collector to provide process steam in an industrial environment. The experiment is continuing through November 1982 under direct Department of Energy management.

The form of the experiment was an industrial field test. Subsequent to verification testing of a PKI system at Sandia National Laboratory, Albuquerque (SNLA), a plant was erected at Capitol Concrete Products, Topeka, Kansas. The parameters to be measured included performance variables, failure modes, and operability in an industrial environment.

Experience to date conclusively demonstrates that the PKI design is capable of producing usable process steam in an industrial environment. The design scores high on operability and compatibility with plant operations. A series of system and plant failures were resolved and field improvements implemented to achieve an operating plant. Since the formal conclusion of JPL participation, two months of unsupervised user experience has demonstrated the effectiveness of installation, check out, and troubleshooting sponsored and managed by JPL. Lessons learned have also been incorporated into two plants installed at Hill AFB, Utah, and Cornell University, NY.

Limited information on performance indicates overall plant efficiencies of 60 to 80% at direct insolation levels greater than 600 watts per square meter. The major unresolved question generated by the experiment is that of the precise optical characteristics of the collector as a function of initial focus and of sun elevation angle.

Applied Concepts tentatively concludes that the PKI design is technically feasible for certain industrial applications, as represented

by the Capitol Concrete plant. We recommend that a thorough evaluation be made, under controlled conditions, of system performance as a function of insolation, site and application variables in order to define system limitations (and thus to identify preferred applications and sites) before proceeding to system readiness testing. We also recommend continued operation of existing plants and installation of additional plants with known, compatible sites and requirements, to gain additional operating experience and longevity information on this attractive alternative energy design.

APPLIED CONCEPTS CORPORATION

Table of Contents

APPLIED CONCEPTS CORPORATION

APPLIED CONCEPTS CORPORATION

List of Figures

APPLIED CONCEPTS CORPORATION

I. Introduction

A. Origins

In early 1980 the Point Focussing Thermal and Electric Applications Project of NASA's Jet Propulsion Laboratory issued a request for a proposal which sought "complete, integrated, low cost experiments designed by industry in which the contractor would provide site, user, system, and all services necessary to design, fabricate, install, check-out, operate, maintain, and evaluate an experimental plant." Forming a team with Power Kinetics, Inc. (PKI) of Troy, New York and Capitol Concrete Products, Inc. (Capitol Concrete) of Topeka, Kansas, Applied Concepts Corporation submitted its proposal to install and evaluate two, single dish, process steam plants using a collector design which had been developed and tested in prototype by PKI. A fourth agency, the University of Kansas Center for Research, Inc. (CRINC) was proposed to be a consultant to the user.

As the result of a competetive evaluation of proposals, the Applied Concepts Team was awarded on December 30, 1980, a contract to install and evaluate the nation's first point focussing industrial steam plant. There were several unique features about this experiment that are worth recalling two years later:

1) It was designed to elicit new ideas from the private sector, and especially from the small business community to augment a well established, JPL program emphasizing small community electric power plants.

2) It was the first JPL project to emphasize thermal applications for point-focussing technologies. This emphasis made feasible the following two points.

3) It was to be a low-cost experiment. Total project resources to the contractor's team have been less than $300,000 per year over the two-year experiment, including funds subsequent to termination of JPL involvement in the experiment.

4) It was the first point-focusing experiment to be moved from the laboratory and the laboratory test site into the industrial sector.

In short, the "Thermal System Engineering Experiment" was designed to be an innovative, efficient, and constructive step toward the exploitation of point focusing technologies to meet the needs of an important energy-consuming sector.

It should be noted that the experiment was regarded by JPL project management to be a system feasibility field test. This is the third step in a five-step model of technology development which includes:

1) Technical feasibility of components
2) Technical readiness of components
3) Technical feasibility of system
4) System readiness
5) Commercial (plant) readiness.

The objective of the experiment can be summarized in the form of a desirable outcome: As stated in the experiment's Plant Evaluation Plan (Applied Concepts' TR J02-04-81, dated November 18, 1981), "As a result of a successful experiment leading to a high level of confidence in system performance and operability in an industrial environment, the PKI system will be considered ready to undergo both operational and economic evaluation at a user's site, employing a system which incorporates the lessons learned during system feasibility testing. The Capitol Concrete experiment represents the first operation of the PKI collector outside of a controlled environment."

B. Non-Technical Overview of the Project's Progress

Over the two years since the submission of proposals for the Thermal System Engineering Experiment, there have been several changes in the locations and management of the experiment which have impacted its course. Most especially, the transfer of the experiment from JPL management to DOE management contemplated for April, and effected in June 1982, came at an awkward time from the standpoint of experiment evaluation, because stand-alone operation of the plant had not yet been achieved. In other words, at the conclusion of on-site support activities under the JPL contract, it was still unclear as to whether technical feasibility of the system in an industrial environment would be a demonstrated result of the experiment.

During July and August 1982, as a direct result of engineering performed under JPL contract during the period January to May, the first and key step toward establishing system technical feasibility was accomplished, as the Capitol Concrete Plant successfully performed under conditions of a two-week supervised, automatic operation. The plant has been continuously operated (as of September 1982) by Capitol Concrete since that time.

Applied Concepts is also installing as of September 1982, a second plant, using a refurbished and improved PKI collector at the USAF Worldwide Landing Gear Overhaul Facility at Hill AFB, Utah. The collector became available as a direct result of this experiment. This installation will be the first point focussing thermal plant where cost will be born totally by the user. It represents a step forward to the establishment of system readiness, according to the technology development model discussed in Section IA. The installation for USAF depends heavily on the results of this JPL experiment.

Applied Concepts and PKI had originally hoped to install plants at two separate industrial sites in the West and mid-west. However, one of the intended industrial users withdrew from the experiment before the award was made, citing corporate retrenchment due to the national economy. JPL and Applied Concepts agreed, therefore, to install the second plant at the Parabolic Dish Test Site at Edwards AFB, California. It was decided to use the funds which could be saved as a consequence of the change to conduct an experiment at the test site which would characterize wind loading on the collector in order to better understand foundation structural requirements and reduce the future costs of industrial installations.

In August 1981, JPL directed on behalf of DOE, that the test site installation be changed to Sandia National Laboratories, Albuquerque, New Mexico (SNLA). This was done, but subsequently, due to the massive budget reductions of 1981 and 1982, the resources were not made available for adequate supervision and maintenance of the SNLA experimental plant. The system was operated during the month of November 1981, by a technician trainee, but operations ceased when repairs requiring a higher level of maintenance became necessary. As a consequence, the wind loading experiment was never conducted. It is this SNLA system which was ultimately dismantled to become the nucleus of the plant for installation at Hill AFB.

Operation of the Capitol Concrete Plant was originally envisioned for the first quarter of FY 1982, and installation was accomplished in November 1981, with first steam produced at that time. A combination of four factors, however, led to a delay in plant operation until July 1982. These were:

1) A cautious attitude toward the conduct of an experiment within an industrial setting and a desire to maximize reliability and to minimize unanticipated operational consequences on the plant owner.

2) A scarcity of funds due to changing national priorities. This practically meant that all unanticipated problems had to be solved within the original budget.

3) A contractual vehicle which proved to be unwieldly in that four to twelve weeks administrative delay was introduced in approving the use of available funds for contingency applications.

4) The seasonal problems of solar plant check out in Kansas from December through March.

As a result of the time consumed in the solution of these problems, and the change of project management in June 1982, it is impossible to prepare a final report which is truly "final." That will have to await the completion of DOE contract DE-AC04-82AL20601, currently scheduled for December 1982. It should be noted that this was the originally scheduled time for completion of the JPL contract, and for submission of this final report.

This final report under the JPL contract, therefore, must deal primarily with lessons learned during the process of the experiment through May 1982. A small amount of plant performance information is available from the brief operation of the Albuquerque plant. In addition, we can confidently state based on over 50 days operating experience under the subsequent DOE contract, that the process which is being reported here was ultimately a successful one. The lessons learned in the course of plant manufacture, installation and check out did lead to a solution of those problems which were encountered, and ultimately to a solar steam plant functioning in an industrial environment.

II. Results of the Thermal System Engineering Experiment

A. Reporting Requirements and Content

According to Data Requirement Description (DRD) No. TE07, of the contract, this final report shall include the following information:

1) Test results and discussion for all accomplished tests with special emphasis given to issues of reliability, safety, operations and maintenance, factors affecting plant installations and any unusual or previously unreported problems.

2) The discussion of how the plant evaluation plan was implemented and the success in achieving each of the objectives.

3) Discussion of recommended improvements to plant or subsystem design where appropriate.

4) Discussion of failure modes of the system.

5) Identification of additional experiments or operating modes, where necessary, to completely characterize the system.

During the course of the truncated experiment, the following reportable activities were accomplished:

1) Testing. Check-out testing was performed at SNLA and at Capitol Concrete Products according to the contractor-prepared "Check-Out Test Plan." Verification testing of general system performance was conducted at SNLA according to the contractor prepared "Verification Test Plan." The results of these tests will be analytically reported here (Section IIB).

2) Because of the fact that plant operation did not begin before program responsibilities were transferred to DOE, the Plant Evaluation Plan was never fully implemented. A brief discussion of each of the objectives and such information as has been developed during installation and check out is presented here (Section IIC).

3) Improvements in plant and subsystem design have been identified during the course of this experiment, some of which have been incorporated into the design for the Hill AFB plant. These changes will be discussed in Section III of this report.

4) Records were kept of all plant failures during the installation, check out, and verification testing period, as reported monthly to JPL. These problems and their resolutions are reported here, as an element of plant evaluation (Section II,C,3).

5) As a result of experiment progress to date, it is possible to identify additional experiments to completely characterize the system's potential for industrial energy conversion applications. Conclusions and recommendations are included in Section IV below.

B. Test Results and Discussion

1. Check-Out Testing

Check out testing was performed in order to uncover any problems requiring attention prior to plant start up. Component level check out was performed by PKI on a test-bed system which was erected at the PKI test-site near Troy, New York, prior to installation of the Albuquerque plant. Component and system level testing were conducted at the SNLA test site collector. Component, system and plant level check out were performed on the Capitol Concrete Plant.

Check out testing was more than a routine procedure because the plants which were installed under this contract represented a pioneer effort in solar steam plant installation. Although PKI had built and previously operated five related solar energy systems, the SNLA and Capitol Concrete designs included significant, untested improvements upon the prototype, fifth generation model. This prototype was itself a departure from earlier models.

The specification of an industrial installation imposed even greater significance to check out testing. Reliability, maintainability, and operational safety had never before been primary requirements for the PKI system, which had been used only as a laboratory device.

A "Check-Out Test Plan" (Applied Concepts' TR J02-01-81, DRD No. TE02, dated August 20, 1981) was prepared by Applied Concepts incorporating input from PKI and review comments from PKI and JPL. The plan was divided into three stages:

1) Component Level Testing
2) System Level Testing
3) Plant Level Testing

The plan was based upon system design, operational concept, and experience with the fifth generation prototype, since no previous operational experience was available. Tests and procedures were improved or modified in the field, according to actual conditions, by the project engineer. These tests, as performed, are reproduced in Appendix A of this report. Lessons learned about check out procedures have been incorporated into the check out test plan for the Hill AFB installation.

It is the nature of a check out test that all of its specifications be met prior to plant operation. The results of testing, therefore, were that all check out test criteria were met. This accomplishment was more exciting in its performance than in its statement, because of the engineering, design, and construction problems which the process

of testing revealed. Each of the problems was resolved as it occurred, however, and all criteria were satisfied at the Capitol Concrete plant by July 1982.

Check out was conducted in three phases. Component level testing was conducted during the installation process. System level testing was conducted subsequent to installation. Plant level testing was conducted at Topeka subsequent to final system check out, during a period of supervised plant operation.

a) Component Level Testing

Component level testing at Capitol Concrete took place during the period November 2 through November 23, 1982, subsequent to similar procedures at Troy and at SNLA. Problems which arose were solvable by field engineering or repair on the spot. The problems detected in this phase were relatively minor, consisting of such things as detection of a bad battery, a need to re-drill a hole in adjustment plates, discovery of an inadequate boiler gasket, etc. In each case, the fault was corrected as detected, and the changes incorporated into PKI's information base. Similarly, the lessons learned during component level check out testing at PKI and SNLA were incorporated into the components installed at the Capitol Concrete plant.

None of the problems detected during component level testing were of a nature to present a barrier to operation at the system level, subsequent to field improvements. None of the improvements made were of a generic nature which should be of value to manufacturers other than PKI. This means that component level corrections were either specific to a PKI design or process (e.g., concerning the mounting materials for the square mirror tiles) or trivial (e.g., replacing a bad battery).

b) System Level Testing

System level check out was conducted at SNLA during the period October 8 through November 12, 1982. System operation was by Applied Concepts personnel, with the assistance of Brian Beveridge of the JPL staff. A summary of the problems uncovered and resolved is presented in Figure 1.

System level testing at Capitol Concrete began on November 23, and evolved into an extended process due to weather and multiple interactions as corrections were made, the system re-checked, and new problems discovered which were masked by the earlier set of problems or the low level of operation. For much of the period, the system was usable and if in a laboratory environment, would have been run under supervision to gain experience with the system. Because the expense of maintaining an engineering staff in Topeka was beyond program resources, and because of a reluctance to ask Capitol Concrete personnel to operate the system until it was fully checked out and operational, the project team utilized the approach to system check out as presented in Figure 2.

Figure 1: System Level Check Out Summary, SNLA

Period: October 8, 1981 - November 11, 1981

Problems Detected

1. a. System: Mirror Assemblies
   b. Diagnosis: Adjustment plates work loose causing defocus and leading to drive failure.
   c. Action: Modify design and replace.

2. a. System: Fluid Loop
   b. Diagnosis: Failure of level switch due to magnetic particle build-up.
   c. Action: Clean boiler. Recurrence of problem ultimately led to a redesigned, mechanical level switch.

3. a. System: Fluid Loop
   b. Diagnosis: Leak in feed water line.
   c. Action: Use smaller clamp.

4. a. System: Control
   b. Diagnosis: Flux trap melt caused by operator error in manually over-riding elevation mode, while azimuth tracking was in automatic during reinitialization of control system.
   c. Action: Change reinitialization logic to prevent over-ride possibility.

Figure 2: System Check Out Procedures - Capitol Concrete Plant

Location		Event
Topeka	1)	Conduct system check out
Topeka	2)	Identify systemic problem(s)
Troy/Boulder	3)	Characterize and develop solution to problem.
Troy/Boulder	4)	Procure hardware and design fix to problem.
Topeka	5)	Implement fix.
Topeka/Boulder/ Troy	6)	Wait for sufficient insolation to conduct check out.
Topeka	7)	Conduct component check out as required.
Topeka	8)	Conduct system check out (=1, above).

In any event, three iterations of this sequence was required to achieve a level of confidence necessary to proceed to plant level check out testing. Usually the most frustrating and time consuming step was step 6. A summary of the problems uncovered and resolved at each step is presented in Figure 3.

APPLIED CONCEPTS CORPORATION

Figure 3: System Level Check Out Summary, Topeka

Period: 23 November 1981 - 10 March 1982

Problems Detected

1) a. System: Data Acquisition System: Fluke-Apple Interface
   b. Diagnosis: Miswiring due to manufacturer misdocumentation
   c. Action: Rewire interface

2) a. System: Fluid Loop, Pump Package
   b. Diagnosis: Poor placement of drain-down valve
   c. Action: Field modification

3) a. System: Control System, Flux Trap Sensors
   b. Diagnosis: Additional sensors required
   c. Action: Installed four additional sensors on flux trap

4) a. System: Control System, Receiver Over Temperature Process
   b. Diagnosis: Logic and hardware incompatibility judged inadequate for safe operation
   c. Action: Design and install a diagnosing, latching stow

5) a. System: Receiver
   b. Diagnosis: Magnetic level switches fail to operate due to build up of magnetic particles
   c. Action: Replace with mechanical switch and low water cutoff

Figure 3: System Level Check Out Summary, Topeka (Continued)

Period: 18 March 1982 - 30 May 1982

Problems Detected

1) a. System: Fluid Loop, Pump Package
   b. Diagnosis: Flow meters fail to operate properly
   c. Action: Exchanged with repackaged unit from SNLA. Indicator lights added to display solenoid valve conditions

2) a. System: Fluid Loop, Drain Down
   b. Diagnosis: Pockets of water in low spots which could freeze and form plugs
   c. Action: Upgrade installation of fluid lines, pipe supports and insulation

3) a. System: Control
   b. Diagnosis: Electro-magnetic interference in control system
   c. Action: Improve wiring and grounding

4) a. System: Control
   b. Diagnosis: Software inappropriate for maximum safety. Existing method would drain boiler and maintain focus for about 10 minutes before initiating stow if, simultaneously, temperature drops to 40°F and insolation to 600 w/m^2.
   c. Action: Software revised

APPLIED CONCEPTS CORPORATION

Figure 3: System Level Check Out Summary, Topeka (Continued)

5) a. System: Elevation Drives
   b. Diagnosis: Limit switch failure due to design oversight
   c. Action: Limit switches changed. Potentiometer moved to directly linked position

6) a. System: Data Acquisition
   b. Diagnosis: Fluke display & Apple clock inoperative
   c. Action: Hardware replaced, and new software written to be compatible with new equipment

Period: 31 May 1982 - 20 July 1982

Problems Detected

1) a. System: Control System - Acquisition Sequence
   b. Diagnosis: Conflict between new placement of elevation shadowband and acquisition software
   c. Action: Relocate shadowband

2) a. System: Overall PKI System
   b. Diagnosis: Substantive seasonal variation in focus in azimuth as a function of sun elevation, exaggerated due to late November initial focusing.
   c. Action: Field modification of standoffs and refocus at median sun elevation.

Period: 20 July - 26 July 1982

Problems Detected: None

APPLIED CONCEPTS CORPORATION

c) Plant Level Testing

Plant level check out testing consisted of a two-week period of supervised operation at Capitol Concrete, subsequent to the satisfactory completion of all system level tests. This was accomplished during the period July 26 - August 8, 1982, under contract to DOE. The plant performed automatically during the period with no observed problems. On August 8, the operation of the plant was turned over to Capitol Concrete Products.

2) Verification Testing

Verification testing was performed at SNLA during the period October 29 - November 19, 1981. The purpose of verification testing was to verify general system performance specifications and to uncover in a laboratory environment any potentially serious defects in collector design, component compatibility, or fabrication technique. Testing was accomplished according to Applied Concepts' Technical Report J02-03-81, DRD No. TE01, "Verification Test Plan," dated October 13, 1981.

Verification testing was conceived as consisting of two parts. Peformance testing would verify that the PKI system could meet general energy output requirements. Operability testing would verify the system's reliability, availability and maintainability.

The criteria for verification performance testing were established as follows:

1) Plant Steam Quality: 100% saturated steam @30-60 psig.

2) Plant Thermal Power Output: Average $\geq$ 100,000 BTU/hr for hours when insolation exceeds 0.6 kw/m^2.

3) Plant Parasitic Power: $\leq$ 2% of output.

4) Average Plant Efficiency: $\geq$ 50%.

5) Plant Performance Envelope: No set criterion.

The Duration Criterion for a valid test was established to be $\geq$ 10 hours operating time over an anticipated 7 day verification testing period.

It was intended that, subsequent to verification performance testing, the SNLA plant be operated for an additional period under supervision to evaluate plant operability. The criteria for operability had been established by JPL to be:

1) Forced Outage Rate: 0.25

2) Receiver Degradation: Not established. To be measured.

3) Mirror Reflectivity: Not established. To be measured.

The principal criteria of Verification Testing were met and exceeded, as set forth in Figure 4.

Funds were not available to maintain the plant throughout the proposed period of operability testing. It should be noted that the objectives of operability testing could also be met through evaluation of the Capitol Concrete plant.

ORIGINAL PAGE IS OF POOR QUALITY

Figure 4: Verification Test Results Summary

	Criterion	Goal	Performance
1.	Plant Steam Quality	100% Sat Steam @30-60 psig	100% Sat Steam @30-60 psig
2.	Plant Thermal Power Output	$\geq$ 100,000 BTU/hr	159,000 BTU/hr
3.	Plant Parasitic Power	$\leq$ 2% output	0.5% output
4.	Average Plant Efficiency	$\geq$ 50%	69%
	Duration	10 hrs over 7 days	31 hours over 7 days

A more detailed performance chart is presented in Figure 5.

Figure 5: Daily Performance During Verification Testing of PKI Collector at SNLA (1981)

DATE	HRS OF OPERATION ($I \geq 0.6$ kw/m^2)	INSOLATION (kw/m^{2}hr) NORMAL INCIDENT	INSOLATION (kw/m^{2}hr) HORIZ SURFACE	AMBIENT TEMP (°C)	STEAM TEMP (°C)	WATER INPUT (gal/hr)	ENERGY INCIDENT (Btu/hr)	ENERGY OUTPUT (Btu/hr)	$\overline{\text{Eff}}$	PEAK DAILY Eff
11/08	5	0.86	0.49	14.68	139.43	18.59	235000	142000	0.60	0.74
11/09	4	0.93	0.56	14.28	142.44	20.80	255000	186000	0.73	0.77
11/10	4	0.93	0.55	13.60	152.15	22.20	254000	200000	0.79	0.84
11/13	2	0.87	0.47	19.81	140.28	18.00	238.000	162000	0.68	0.71
11/17	7	0.81	0.47	16.81	134.70	16.50	223000	149000	0.66	0.73
11/18	7	0.88	0.52	14.38	135.28	17.97	242000	157000	0.65	0.79
11/19	2	0.81	0.58	8.60	135.34	17.95	220000	160000	0.73	0.75
	TOTAL	AVERAGES								
	31	0.87	0.52	14.59	139.95	18.84	239000	159000	0.69	0.76

Another objective of Verification Testing was to uncover potentially serious defects in collector design, component compatability, and/or fabrication. This aspect of testing, which was integrated with system level check out testing, was successful as three serious defects were uncovered and consequently corrected, as follows:

1) <u>Boiler Manufacture</u>: A head gasket with a temperature rating of only 180°F had been utilized by the component manufacturer. The gaskets were replaced.

2) <u>Level Switch Fouling</u>: High and low level switches in the boiler were found to have very short service lives due to fouling. A cleaning step was added to the boiler manufacturing process and scavenger magnets were employed. Subsequent operation at Capitol Concrete showed that these steps were insufficient to prevent recurrence of the problem, although they did extend component lifetime. Subsequently, mechanical level switches were installed.

3) <u>Elevation Drive Shaft Misalignment</u>: It was learned that the angular alignment of drive shafts must be within a tolerance of ±1°. Due to a manufacturing error, some alignments were within only ±5°. New mirror adjustment plates were installed, and a new adjustment plate was subsequently designed for future installations.

Operability verification testing was to have been accomplished by monitoring system operation at SNLA subsequent to performance testing. Because JPL and Applied Concepts program management agreed that resources were better committed to ensuring the attainment of overall program objectives at Capitol Concrete Products, all testing was halted at SNLA on December 3, subsequent to a plant failure in December 1981 induced by operator error.

Verification performance testing at SNLA provided confidence in the ability of the PKI design to efficiently convert sunlight into usable thermal energy under favorable conditions of insolation. It provided an opportunity to identify problems in design and manufacture prior to installation at Capitol Concrete Products.

C. Plant Evaluation Plan: Implementation and Success

The Thermal System Engineering Experiment "Plant Evaluation Plan," (Applied Concepts TR J02-04-81, DRD No. TE05, dated November 18, 1981) was based upon guidance provided by JPL as per the approved JPL Field Test Implementation Plan. These documents established nine objectives for the Capitol Concrete experiment:

1. Verify that the PKI collector system can produce usable thermal energy from solar radiation.

2. Determine to what extent the experimental plant contributes to meeting the energy requirements of the load at Capitol Concrete Products.

3. Characterize plant performance as a function of insolation, weather, operations and maintenance activities, and environmental factors.

4. Provide accurate input data to performance, cost, and energy/economic impact models.

5. Understand the failure modes of the PKI collector system.

6. Provide feedback to the system-level hardware and software processes.

7. Identify and quantify the impact of operating the experimental plant on the daily operations activities of user personnel and on user manning requirements at Capitol Concrete Products.

8. Identify the impact, if any, of the installation and operation of an experimental plant on the local environment.

9. Identify the impact, if any, of the installation and operation of the PKI collector system on potential acceptance of commercial units by local officials.

Plant evaluation was to have been accomplished by assessing twelve months routine operation of the solar plant at Capitol Concrete Products. Three different evaluative approaches were required to achieve the objectives of the experiment. Thus, plant evaluation was to proceed over the twelve-month period through:

1. Performance Testing (Objectives 1-4)

2. Operability Testing (Objectives 7-9)

3. System Failure Analysis (Objectives 5 and 6)

Because JPL management of the experiment was ended before routine operation began, formal plant evaluation as anticipated was never undertaken. It is possible, however, to address informally some of those issues and objectives which the Plant Evaluation Plan was designed more rigorously to test. The following discussion briefly describes performance issues, operability issues and system failure analyses based on lessons learned during the period November 1981 through May 1982, with some references to pertinent experience subsequent

to the transfer of the experiment to DOE management.

1. Performance Testing

Performance testing was to satisfy four objectives:

a. Verify that the PKI collector system can produce usable thermal energy from solar radiation.

b. Determine to what extent the experimental plant contributes to meeting the energy requirements of the load at Capitol Concrete Products.

c. Characterize plant performance as a function of insolation, weather, operations and maintenance activities, and environmental factors.

d. Provide accurate input data to performance, cost, and energy/economic impact models.

Because of the lack of operating experience to date, only the first objective has been reasonably satisfied. Operation at SNLA in November 1981, and at Capitol Concrete Products since July 1982 have verified the PKI collector system's ability to produce usable energy.

Such performance data as was generated before May 31, 1982, is presented in Figures 4 and 5. Subsequent experience indicates that it may be difficult to precisely quantify performance in an industrial environment. There are three contributing factors:

a. Environmental: The support and maintenance requirements of a precise data acquisition system (DAS) are higher than those of the collector. Although the collector is compatible with the procedures and conditions of a concrete masonry block plant, it is more difficult to maintain test equipment on a continuous basis in an industrial plant. This issue might be of less importance in special settings, e.g., high technology applications where laboratory scientists are available.

b. Macro-Economic: The recession in the construction industry has atypically decreased the user's energy demand. Solar plant availability has therefore exceeded autoclave operating requirements. In other words, production lines have been shut down. This reduces the value of the solar plant in a way which is difficult to normalize for use in performance, cost, and energy/economic impact models.

c. Institutional: The information which is ideally available on solar energy plant performance through the DAS is much more than is available on the conventional gas-fired boiler or the autoclave which it supports.

As a consequence of these factors, we anticipate that performance estimates may be the most cost effective information to come from the industrial application of this and other solar industrial plants. Where precise performance data is desired, it is probably preferable to go to the expense of operating in a controlled laboratory environment. This could be ultimately less expensive and less frustrating than obtaining precise data from the field. If it had been possible to simultaneously operate the Capitol Concrete Plant and a control system at either the PDTS or SNLA, as once intended, more precise performance data would have resulted. We recommend this approach of operating an industrial plant and a laboratory control for future experiments where performance data is a key objective.

2. Operability Testing

Operability testing was to satisfy three objectives:

a. Identify and quantify the impact of operating the experimental plant on the daily operations activities of user personnel and on user manning requirements at Capitol Concrete Products.

b. Identify the impact, if any, of the installation and operation of the experimental plant on the local environment.

c. Identify the impact, if any, of the installation and operation of the PKI collector system on potential acceptance of commercial units by local officials.

Sufficient experience with the PKI collector system has been gained to allow some preliminary statements regarding operability. The impacts of operating the plant have been minimal in all regards during the first two months of operation (July 26 - September 26, 1982). The plant has been run and maintained by the Capitol Concrete production manager. Weekly maintenance has been reported to average about 1 hour/week. The president of Capitol Concrete reports no undue problems in operation, with no more additional attention required beyond that of any new piece of industrial equipment.

No impacts have been observed on the local environment. No complaints have been received, although the plant is located in an urban industrial setting. According to Capitol Concrete, the system is not noisy and causes no dust or dirt. Concerns about worker distraction due to glare or the bright focal image have not materialized. After a few days, it is reported, plant employees no longer even consciously noticed the glow of the receiver.

Acceptance of the unit by local agencies has been routine. Capitol Concrete has maintained a low profile regarding the plant. In the absence of user publicity, the major reaction has been mild curiosity and interest.

These statements regarding operability should be regarded as tentative until further experience is gained. Nonetheless, the fact that Capitol Concrete has accepted ownership of and responsibility for the plant as of late September 1982, is an indication of its operational compatibility with industrial applications.

3. System Failure Analysis

This aspect of plant evaluation is to be responsive to two objectives:

a. Understand the failure modes of the PKI collector system.

b. Provide feedback to the system-level hardware and software processes.

According to the JPL "Field Test Implementation Plan," failure analysis should include plant failures introduced by poor design, poor workmanship or materials, operator error, environmental factors and vandalism. To date, no failures have been attributed to vandalism.

During limited operation for check out testing and for verification testing at SNLA, from 15 October 1981 through 3 December 1982, a total of eight plant failures were observed. During check out testing at Capitol Concrete from 23 November 1981 through 19 July 1982, a total of nine plant failures were observed. One plant failure has occurred since 26 July 1982 during the period of user operation. Figure 6 summarizes plant failures as reported through September 1982. There is some overlap between these failures and the information discussed in sub-section B above, because most failures occurred during check out and verification testing.

Figure 6: Plant Failure Summary

System	Event	Plant	ID#	Date	Type*	Description
Drives						
	1	SNLA	001	15 Oct 82	D/W	Adjustment plates had low tolerance for accepting variance in angle of elevation drive shafts. Resulted in broken shafts.
	2	CCP	002	Apr 82	D/M	Limit switch on elevation drive failed to work due to inadequate design and a thrown screw.
	3	CCP	003	17 May 82	E/W	Poor attachment of drag links allowed two assemblies to present full sail to 70 mph winds. They broke off drive ends and dropped from structure.
Fluid Loop						
	1	SNLA	002	15 Oct 81	M	180°F gasket provided for 300°F boiler.
	2	SNLA	006	11 Nov 81	W	Leak in feedwater due to mis-sized clamp.
Fluid/Loop Control						
	1	SNLA	003	15 Oct 81	D	Upper level switch failed due to magnetic fouling.
	2	SNLA	004	19 Oct 81	D	Lower level switch failed due to magnetic fouling.
	3	SNLA	008	3 Dec 81	D	Failure of lower level switch due to magnetic fouling compounded by slow-to-stow from overtemp.
	4	CCP	001	9 Mar 82	E/W	Ice plug lead to dry boiler. No stow occurred due to lower level switch. Second level stow occurred from overtemp.

Figure 6: Plant Failure Summary (Cont'd)

System	Event	Plant	ID#	Date	Type	Description
Controls						
	1	SNLA	007	12 Nov 81	H/D	Accidental manual over-ride lead to flux trap melting.
	2	CCP	007	7 Jul 82	H	Broken wire disabled remote elevation drive. Chip failure due to EMI.
	3	CCP	008	9 Jul 82	E	Chip failure due to EMI.
	4	CCP	009	16 Jul 82	W	Faulty thermocouple installation lead to false stow.
	5	CCP	010	19 Jul 82	M	Overtemp stow due to faulty switch. Replaced.
	6	CCP	011	27 Aug 82	E	Chip failure due to EMI.
System Interactions						
	1	CCP	005	27 May 82	D	Seasonal variation in elevation sun angle found to cause variance in azimuth focus.
	2	CCP	004	27 May 82	D	Improper placement of elevation shadowband sensor lead to sun acquisition problems.

* D = design
W = workmanship
M = materials
H = human error
E = environmental

Applied Concepts and PKI discussed each plant failure as they occurred. Diagnosis and solution to the problem was often worked out jointly. In each case, the resolution of the problem was fully known to PKI, which has incorporated the lessons learned into present or proposed system design, as appropriate. Applied Concepts has also benefited from the process, incorporating new materials, designs and methods into the Hill AFB installation.

The following is a brief review of the failure modes by subsystem with a description of the consequential actions taken by PKI or Applied Concepts Corporation. In general, each problem experienced at SNLA was solved through field engineering, with lessons learned incorporated into fabrication for Topeka and subsequent installations. Problems encountered at Topeka were, in turn, solved through field engineering, with lessons learned incorporated into the Hill AFB plant.

a. Drives: The problems associated with the elevation drive system were for the most part associated with departures from the fifth generation prototype. In addition, because these installations were the first which PKI made at a site removed from their base of operations, there was an inevitable learning curve associated with fabrication for field assembly.

As described at the engineering review in March 1981, the elevation drive is the most complex subsystem of the PKI design. For this experiment, the prototype design was modified to reduce complexity and number of parts. The number of drag links, pulley wheels and cables was cut in half. Partly as a result, a new method of attaching cables to drag links was employed. The lead screw assembly, which provides the interface between the elevation motor package and the drag link assemblies, was upgraded and enclosed. Along with these mechanical changes, the elevation motor and drive interface with the controller were incorporated into an integrated

package, and a more efficient focusing procedure was implemented.

Prior to installation at SNLA, the modified elevation drives were tested at PKI but installation under field conditions revealed some areas for improvement.

The two major problems to emerge can be seen to result from the more rigorous requirements for durability and standardization required by industrial plant design. Adjustment plate design, for example, was adequate and performed adequately when installed in matched pairs at PKI by PKI engineers. When shipped in a mixed lot and installed on site, however, excessive angles were formed between the axis of the mirror drive shaft and that of the mirror assembly. The adjustment plate design was inadequate to accept this variation in angle. Field adjustments were made. Design changes were made and tested for the Topeka installation, and further improvements were incorporated into the Hill AFB plant.

Similarly, for the Topeka installation, PKI implemented a change in elevation drive limit switches which changed the switch activator from a mechanical one attached to the drag link to a drive system simulator using chain and sprocket gear reduction and located in the gear box. This approach proved inadequate and unreliable for the field application. As a result, the simulating switches were removed, and two mechanical, direct limit switches were installed on the drives themselves.

The final reported failure occurred when 70 mph winds caught two mirror assemblies full sail, due to poor attachment of the drag links. Due then, to insufficient engagement of the stub shaft on the utboard end supports, the assemblies were twisted off the drive end, and separated from the collector. The two drive shafts were replaced and adjusted. The entire machine was inspected for other trouble spots. None were found.

The typical pattern of failure in the drive system, then, was failure due to the first experience of a previously unencountered stress, either situational or environmental. In each case it was necessary to "ruggedize" the system through improvement of design, of quality control, or of workmanship to meet the requirements imposed by working outside of a controlled environment.

b. Fluid Loop

Except for failures due to fluid loop/control system interactions as described below, no serious problems were experienced with this subsystem. System level testing quickly revealed that a mismatched gasket had been supplied by the boiler manufacturer. This was replaced with a gasket of the proper rating. A mismatched clamp allowed a leak to develop in the feedwater line. The clamp was replaced. No further problems have been experienced.

c. Fluid Loop/Controls

The principal problem encountered with the fluid loop controls was the choice of a magnet activated level switch for input feedwater control. This design consistently failed in operation with the PKI receiver. The failure mechanism was fouling by magnetic particles inside the boiler.

Attempted fixes to the problem included chemical cleaning and flushing of the boiler prior to installation, and installation of scavenger magnets. Both approaches only extended the mean time between failures for the switches from hours to days. Ultimately, the switches were removed and replaced with mechanical, bulb type level switches.

In one case at SNLA, the fluid loop problem was compounded by a dry boiler which resulted in overheating. Because of inadequate design of the over temperature stow sensor, the lack of an integral low water shut down, and the lack of a latching stow, the collector is believed to have cycled between:

1. Heating dry boiler to 360°C.

2. Stow due to boiler over temperature.

3. Cool down by ambient air cooling.

4. Refocus and return to 1, above.

At this time, the sole over temperature stow sensor was located at the boiler outlet. Although set to initiate a stow at 232°C, it was found that the face temperature of a dry boiler could exceed 360°C before the 232°C temperature was exceeded at the outlet.

In any event, no immediately hazardous phenomenon resulted from the failure which occurred during unattended operation. Nonetheless, the potential for danger was obvious. The system design was unacceptable.

In addition to changing the level switches to reduce the likelihood of an empty boiler occurring, the safety system was improved as follows:

1. A low water, sensor activated stow was added.

2. Addition of flux temperature sensors and a flux trap over temperature stow.

3. Addition of a second boiler temperature sensor behind the face of the receiver.

4. Addition of an electronic latching stow device which must be reset to resume collector operation after an over temperature stow is initiated by any sensor.

This improvement was implemented at Topeka and Hill AFB.

A second, serious problem emerged in March 1982 when an ice plug in the feedwater line led to a dry boiler. It appears that the low level stow routine had been accidentally disconnected, or left disconnected, so that the system did not stow until a receiver over temperature occurred. This second level safety routine operated correctly and latched as designed. This incident provided confidence in the improvements made as a result of experience in Topeka. It also led to two further changes:

1. It was determined that the ice plug resulted from improper alignment and insulation of the feedwater lines, allowing water to remain in pockets in the lines after drain down (freeze protection), and then to freeze. Workmanship was upgraded.

2. PKI has stated an intention to add status checks on all safety systems to prevent operation during unintended or accidental overrides.

d. Controls

The most common control system problem has been microprocessor chip failure due to electromagnetic interference (EMI) induced by nearby lightening strikes. Two chip failures have occurred in the control system and one in the data acquisition system. The plant has been regrounded, but failures have occurred subsequent to re-grounding.

The current approach has been to replace chips as the problem occurs. An alternative is to install lightning and transient damping devices at a cost estimated in excess of $1,000 in equipment alone. Further analysis and experience are needed to understand this problem.

The major impact of EMI failure has been irritation. Only a freak phenomenon of lightning during a period of insolation ≥ 0.6 kw/m^2 could lead to safety concerns.

An early experience at SNLA involving an accidental, manual override of the elevation drives while tracking continued in azimuth which led to the only hazardous failure. The incident occurred before flux trap temperature sensors were installed. The full focus of the collector was borne by the eastern flux trap causing melting of the aluminum material. The condition was quickly noticed by the operator, who manually stowed the collector. It was partly as a result of this event that flux trap temperature sensors were installed and the control system improved as described in section IIB3c above.

Several minor problems were reported and fixed. A broken wire at the local/remote switch box disabled the remote (i.e., controller) elevation drive. The break is believed to have occurred unnoticed during a routine maintenance inspection. A misplaced thermocouple (in full sun) was found to have caused a false stow. The sensor was repositioned A faulty upper switch on the flux trap over temperature signal line caused a false stow. The switch was replaced.

e. System Interactions

The two system failures reported under this heading are the most interesting from a technology development point of view and the most critical from the perspective of technology assessment. They were

detected in the final days of JPL contract management, and share the property of resulting from seasonal variations in the optical characteristics of the unique PKI design.

Because of the seasonal effects, the problems were not fully observed until late May, subsequent to installation in late November. It may be, that if the plant had been installed in any other season than winter, that the phenomena would not have been manifested sufficiently to cause plant failures. It is PKI's current hypothesis that this is the case, and there is evidence supporting that hypothesis, as described below.

The elevation shadowband placement interaction with the control logic is the simpler problem, and can be addressed through repositioning the elevation shadowband as was done in Topeka, and/or by changing the sun acquisition sequence logic.

The change in azimuth focus as a function of sun elevation is inherent to the configuration of the collector. Its consequences may be controlled by setting the original focus of the collector only when sun elevation angle (or perhaps simulated sun elevation angle) is close to the median angle for the latitude of the site. Otherwise, PKI will have to consider changes to the configuration of the mirror assemblies as supported by the space frame.

It should be noted that these two phenomena are related to an azimuth drive/control system interaction which has not led to any plant failures, but which complicates the process of re-initializing azimuth focus, as azimuth shadowband output variables also exhibit a seasonal change.

APPLIED CONCEPTS CORPORATION

The elevation shadowband/control logic seasonally dependent interaction was observed when the elevation drives seemed to be cycling between "stow" and "operate", during apparently normal conditions. As illustrated in Figure 7, the elevation drives leave the stow position (7a) driving under control of the elevation potentiometer toward a focussed position (7b). Control cannot be shifted to the elevation shadowband until the sun's light is incident upon the shadowband as a consequence of the rotation of the mirror assemblies. The angle at which control is shifted to the elevation shadowband has been labelled the "HISUN position" (7c) for ease of reference. The HISUN position is a variable which can be set in the controller.

The collector was first focussed in late November when the sun elevation angle in Topeka was low. During daily operation, the mirrors never returned to the HISUN position under normal tracking. As summer approached, however, the sun elevation angle was low in the morning when sun acquisition typically began. Then as solar noon approached, the sun angle and the mirrors as controlled by the elevation shadowband, approached, then reached the HISUN position (7d).

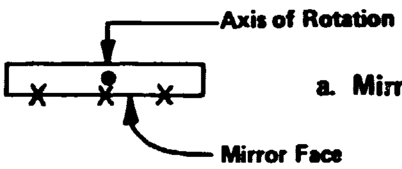
At this point, the control system, "understood" that the HISUN position had not been reached, took over control from the elevation shadowband, and drove the mirrors downward. After the HISUN position was passed and control returned to the shadowband, the mirrors were driven upward to equalize radiation incident on the shadowband sensors. As the HISUN position was passed, the cycle was started again.

A simple resetting of the HISUN position was inadequate, because no angle existed which was low enough to ensure morning or winter sun acquisition and simultaneously high enough to avoid

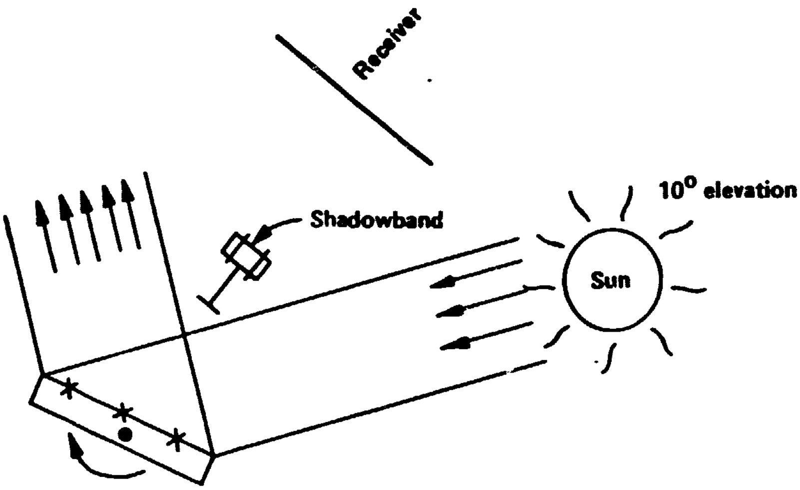
APPLIED CONCEPTS CORPORATION

ORIGINAL PAGE IS OF POOR QUALITY

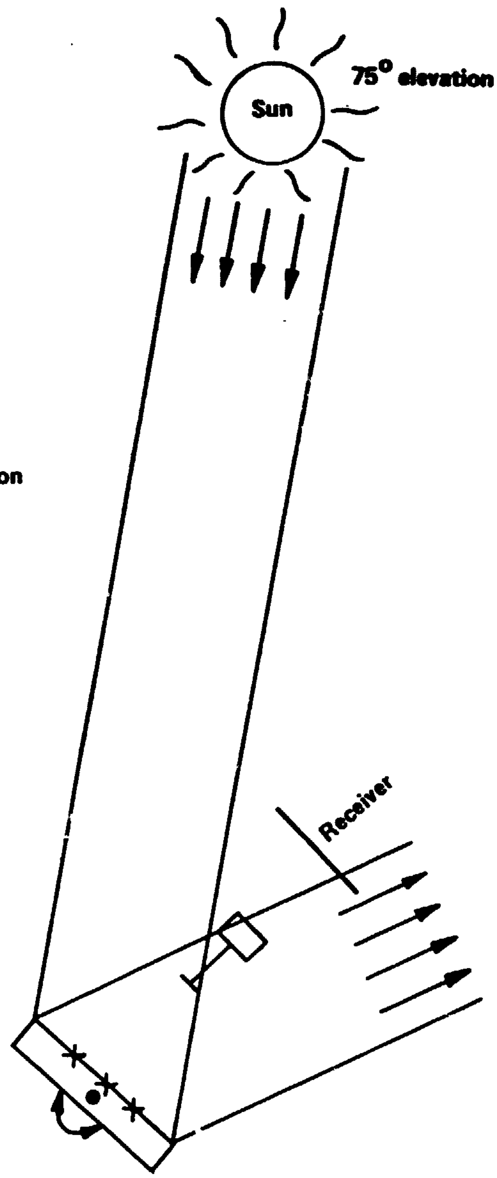
Figure 7. Elevation Drive/Control System Interaction



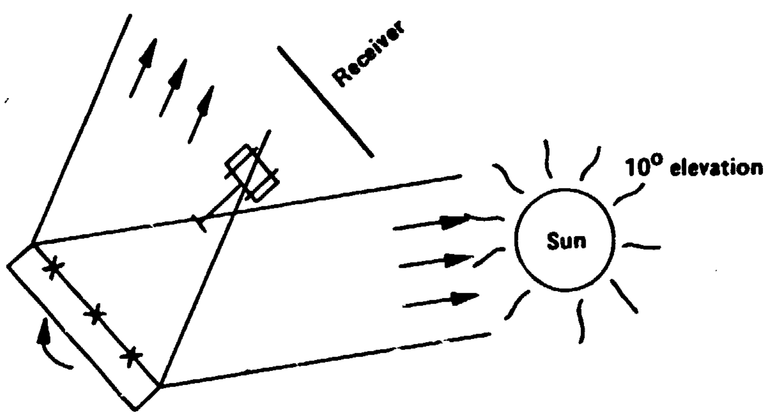
a. Mirror at stow.



b. Mirror driving to HISUN under control of potentiometer.



d. As sun elevation angle increases, mirror returns to HISUN. Control is returned to potentiometer, which drives mirrors downward, then returns control to shadowband, which drives mirror back to HISUN, etc.



c. Mirror at HISUN. Control transferred to elevation shadowband.

transfer of control during tracking.

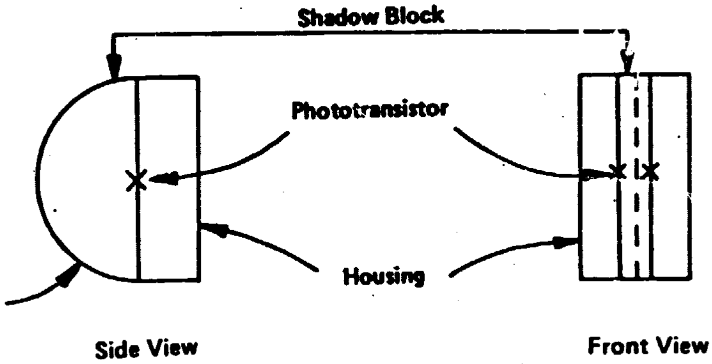
As a result of this experience and diagnosis, the elevation shadowband sensor was moved and the HISUN parameter changed. Operation is now possible at all sun angles between 10° and 75°.

A related phenomenon has been observed regarding the azimuth shadowband/control system interaction (See Figure 8). The initialization of the controller parameters took place in late November, when the shadowband position was also set. For proper operation, the shadowband must be aligned parallel to the plane formed by the angle of the concentrator face with the receiver. The controller parameters must be set so that the phototransistors are equally illuminated when the sun azimuth angle is 90°. If the phototransistors are in a geometrically symmetrical position and have identical electrical characteristics, the system will then work as designed.

When the Topeka collector was set up in November, the shadowband was adjusted to work with the sun at an elevation of 10° to 30°. Inspection of the shadowband during operation in May showed that the shadow cast by the band was no longer a line, but a curve as shown in Figure 8C. The change could be caused by improper setting of the phototransistors, dissimilar electrical characteristics or improper setting of the controller parameters. The pointing vectors of the shadowband set up in this way form a cone.

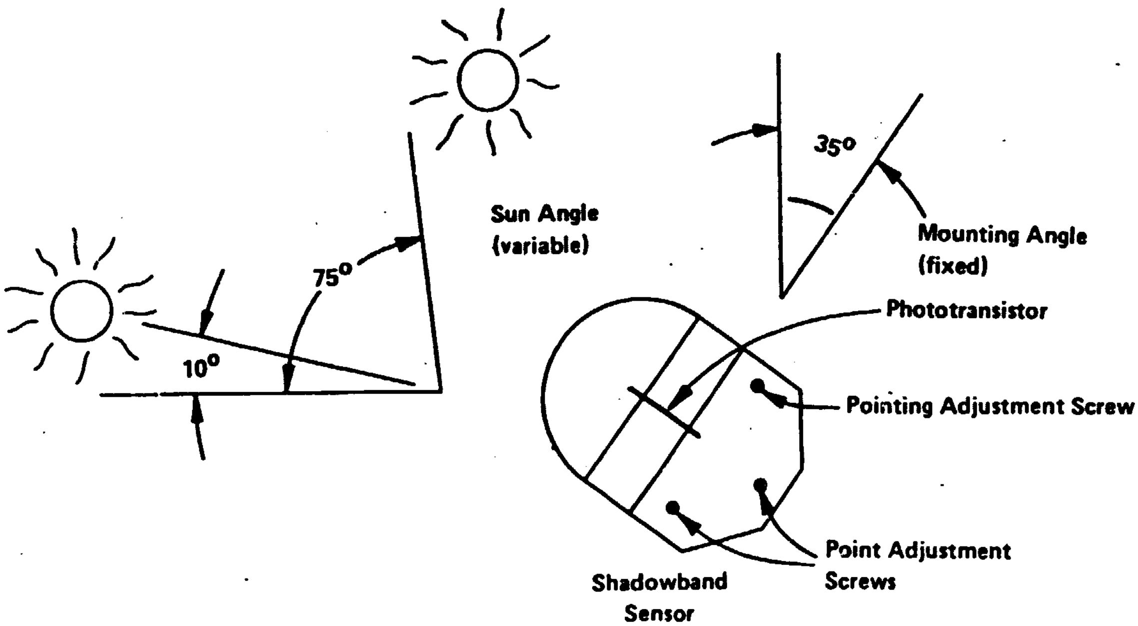
With a small variation in sun angle (Winter operation) the difference in pointing angle is small. With large variations, (Summer operation) the problem is reflected in the locus of focus on the receiver. This phenomenon could be a contributing factor to the second failure mode due to system interactions as described here.

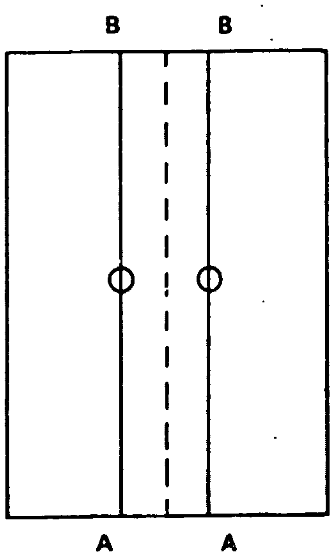
Figure 8. Azimuth Drive/Control System Interaction



a. Azimuth shadowband diagram.

b. Shadowband seasonal angular relationships.

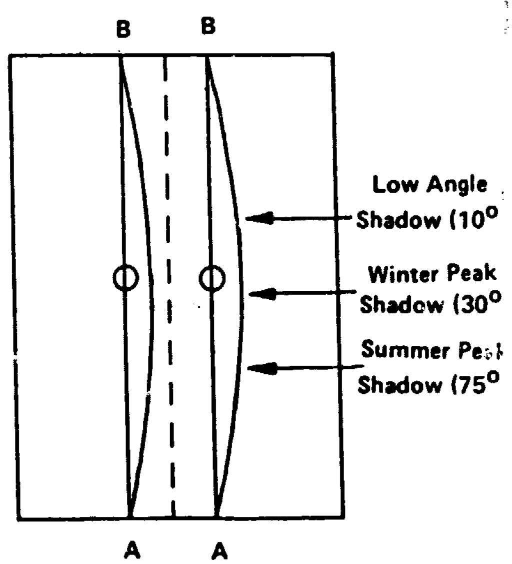




c. Shadowband Appearance.

Left: As set in November. Pointing vectors form a plane.

Right: As observed in May. Pointing vectors form a cone.



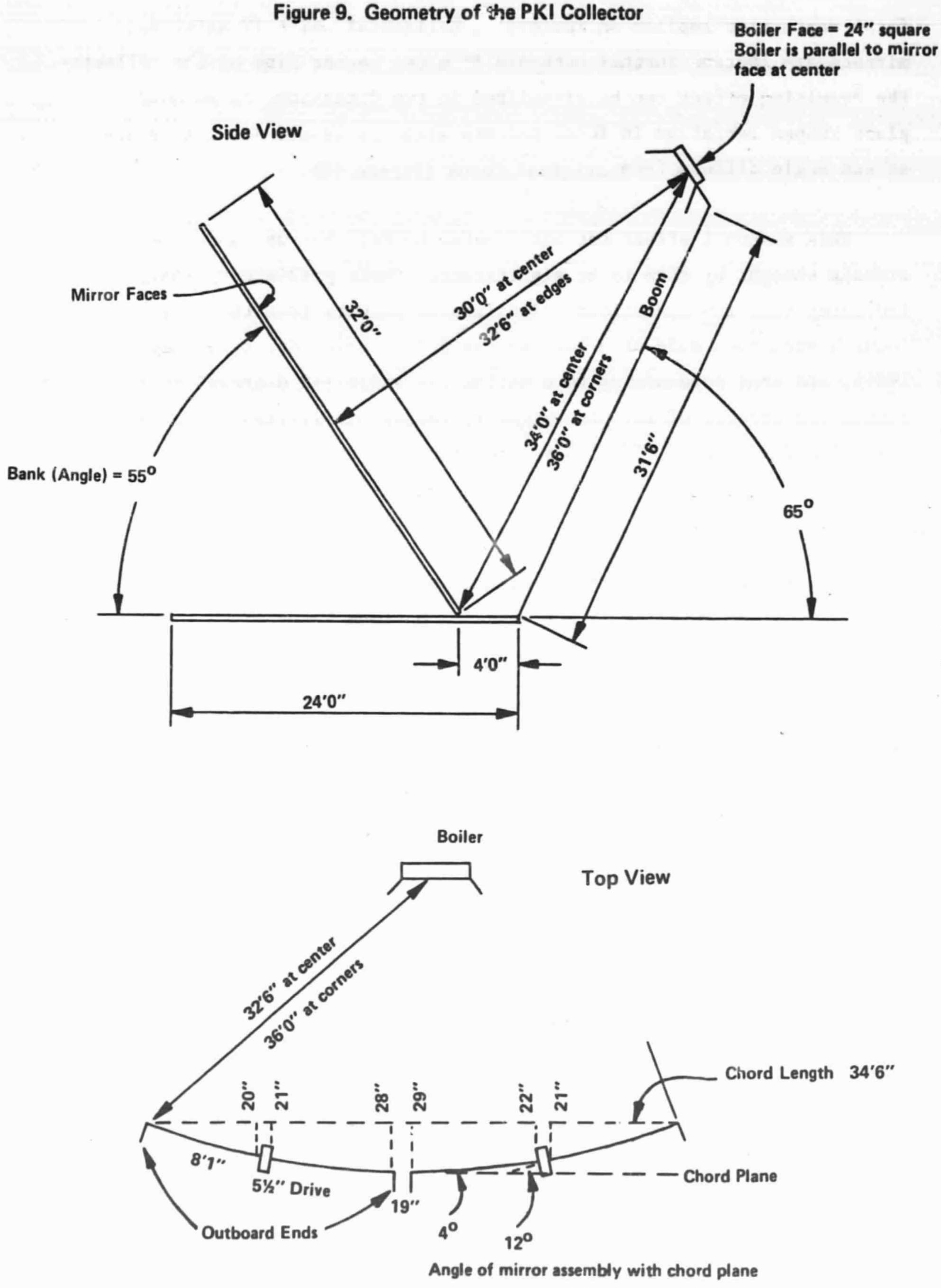
When the Capitol Concrete solar plant was returned to operation in May, following an extended period when subsystem level modifications and repairs were being made, it was found that the collector was no longer mechanically in focus in azimuth. When the azimuth shadowband had positioned the collector properly with respect to the sun, its image was "smeared" horizontally across the collector. Although a mechanical adjustment was necessary to refocus the system, no mechanical mechanism for the defocus could be found.

The focal dispersion in azimuth as a function of sun elevation apparently is optically inherent to the collector configuration. The collector is neither a perfect Fresnel mirror nor a perfect parabolic dish, but shares some of the properties of each. (Figure 9) The system's mathematical description is complex, and a complete analytical optical model does not exist to provide a precise quantitative description of the variation of solar flux in the focal region as a function of the multiple variables involved, including sun angle.

Nonetheless, it is possible to say that the focal depth varies for each row of mirror columns as a function of sun elevation. Each of the 108 mirror columns is focussed independently, upon installation and then locked into a fixed configuration with the other 107 columns which thereafter track as a unit. The focussing procedure used, until this time, was to achieve the tightest possible focus at the time of focus, by visually superimposing the images of each of the 108 columns. Since each column makes a slightly different angle with respect to the sun and the receiver, however, and since the angle varies with sun elevation once the columns are fixed relative to each other, the location of the focal image in space will vary once the sun elevation angle varies.

According to a preliminary optical analysis, the variation is greatest in depth (the Z axis). Because of the relative angle between the receiver and the "plane" of the collector, however, a change in

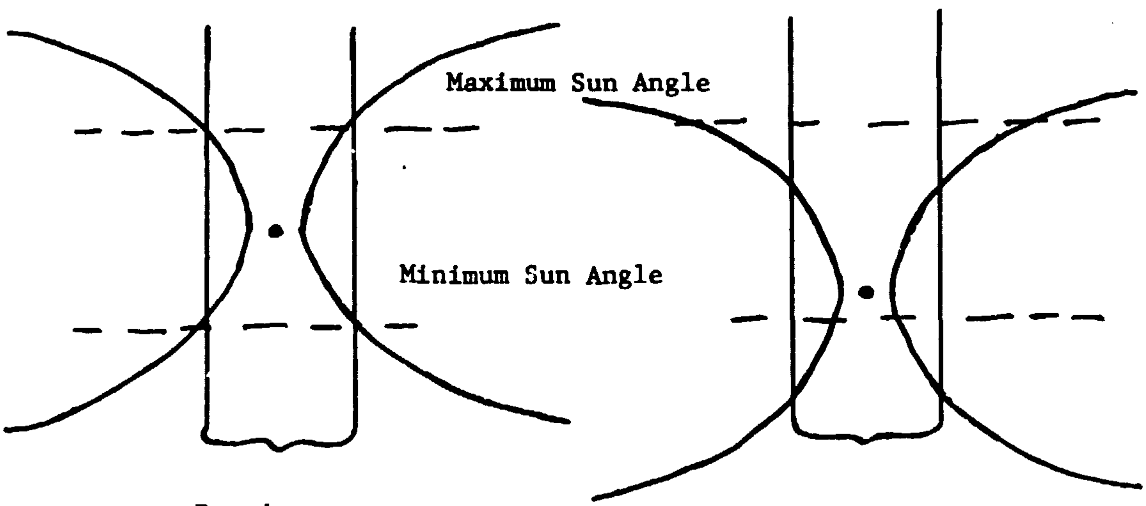
Figure 9. Geometry of the PKI Collector



focal depth also implies an increasing horizontal shift (Y axis) as mirrors are located further outboard from the center line of the collector. The resulting effect can be visualized in two dimensions as an hour-glass shaped variation in focal pattern with the dispersion increasing as sun angle differs from original focus (Figure 10).

This seasonal effect was anticipated by PKI, but was not previously thought by them to be significant. Their preliminary analysis indicates that its operational significance results from the original focus having been made at a low sun elevation angle (during November 1981), and that refocussing to a medium sun angle (42 degrees) will reduce the effects of the phenomemom to reasonable limits (i.e., the loss of a few percent efficiency at extreme sun angles).

Figure 10: Conceptual Diagram of Focal Dispersion as Function of Sun Angle at Optimum Focus



Receiver
<u>Width</u>

Focussed at Medium Sun Angle

Focussed at Low Sun Angle

In accordance with the above diagnosis, the PKI collector was refocuss[illegible] un elevation of 42±3°. This is accomplished by adjusting the st[illegible] Figure 11) of the machine to move one side of a section [illegible] mblies toward or away from the boiler. If the other side [illegible] fixed, the adjustment approximates rotation through an arc. The re[illegible]ing was complicated by the fact that the outermost pair of holes drilled in each standoff had already been used, so that the standoffs had to be field modified to permit refocussing in azimuth. This experience led to the design of a sliding adjustable standoff joint, which was used at the Hill AFB plant.

The Capitol Concrete collector had been initially set up and focussed in azimuth to put the image of each section of mirror assemblies in the center of the boiler at a low sun elevation, nominally 30°. As a result, when sun elevation angles climbed to 75° in mid summer, the images dispersed in azimuth. A first adjustment was made in June 1982 to center the images at a nominal sun angle of 42°. Some spillage of image was still observed at solar noon. To prevent even this much loss of flux, the focusing procedure was modified as per Figure 11c. In this case, all mirror assembly images are not overlapped, but are focussed on different parts of the boiler to ensure flux capture by the boiler throughout the day, as the image focus changes on the boiler face as a function of sun angle. The readjustment was accomplished on July 6.

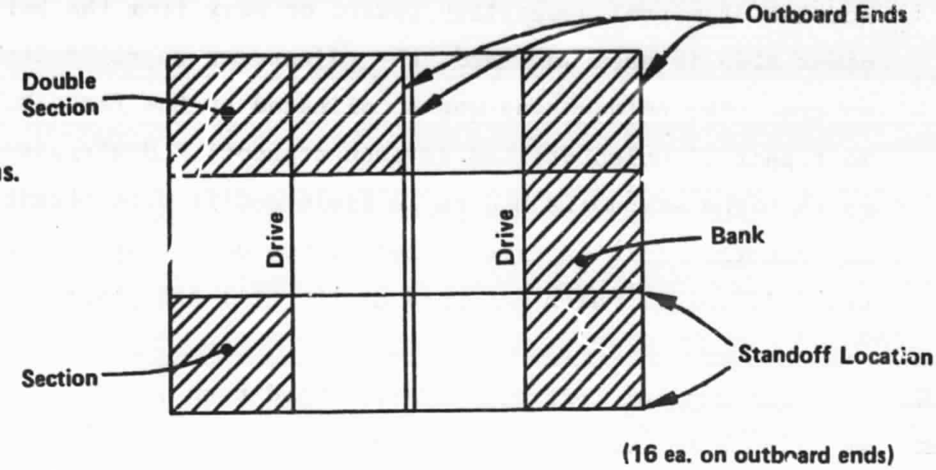
In the absence of mathematical modeling, the overall impact of this phenomenon on PKI collector operation and performance must be assessed through observation. It can be noted that, according to PKI, there has been no evidence of problems encountered in operation of two plants in Troy, NY. Neither of these collectors was focussed in Winter, however, and the seasonal variation in sun elevation is slightly less in Troy than in Topeka (about 4° less). This experience plus the daily functioning of the Capitol Concrete Plant during July from early morning through solar noon until evening leads us to believe that the technical problem has been resolved for systems with receiver apertures of 24" in temperate latitudes.

APPLIED CONCEPTS
CORPORATION

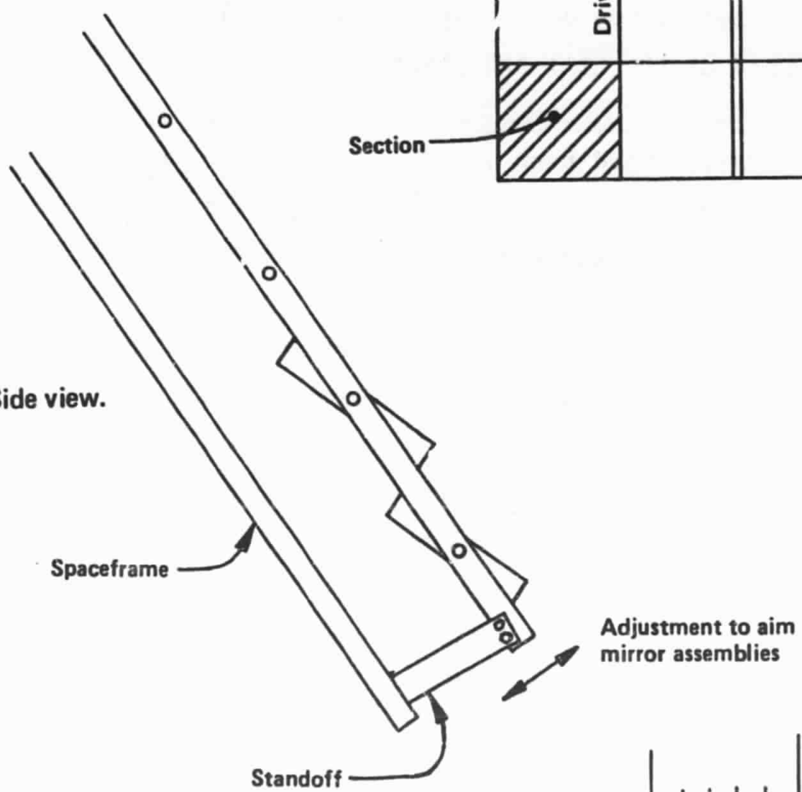
ORIGINAL PAGE IS
OF POOR QUALITY

Figure 11. Azimuth Refocus Procedures

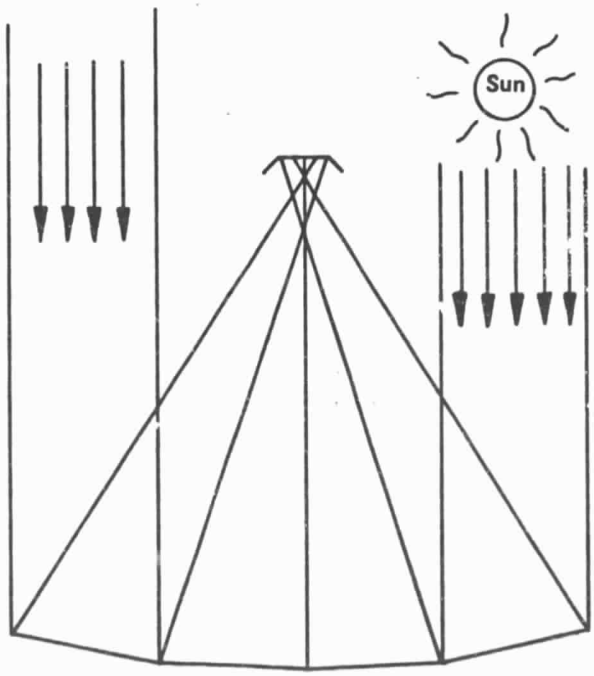
A. Face view and definition of terms.



B. Side view.



C. Final focus strategy
(Sun Elevation 42$\pm$3°)



For smaller receivers or for more southerly installations, the problem of seasonal variation in azimuth focus may have to be reconsidered. Design changes may be necessary to change or make readily adjustable collector geometry. Methods to focus the collector in Winter should also be considered.

III. Improvements in Plant and System Design as a Result of the Experiment.

A. System and Plant Design

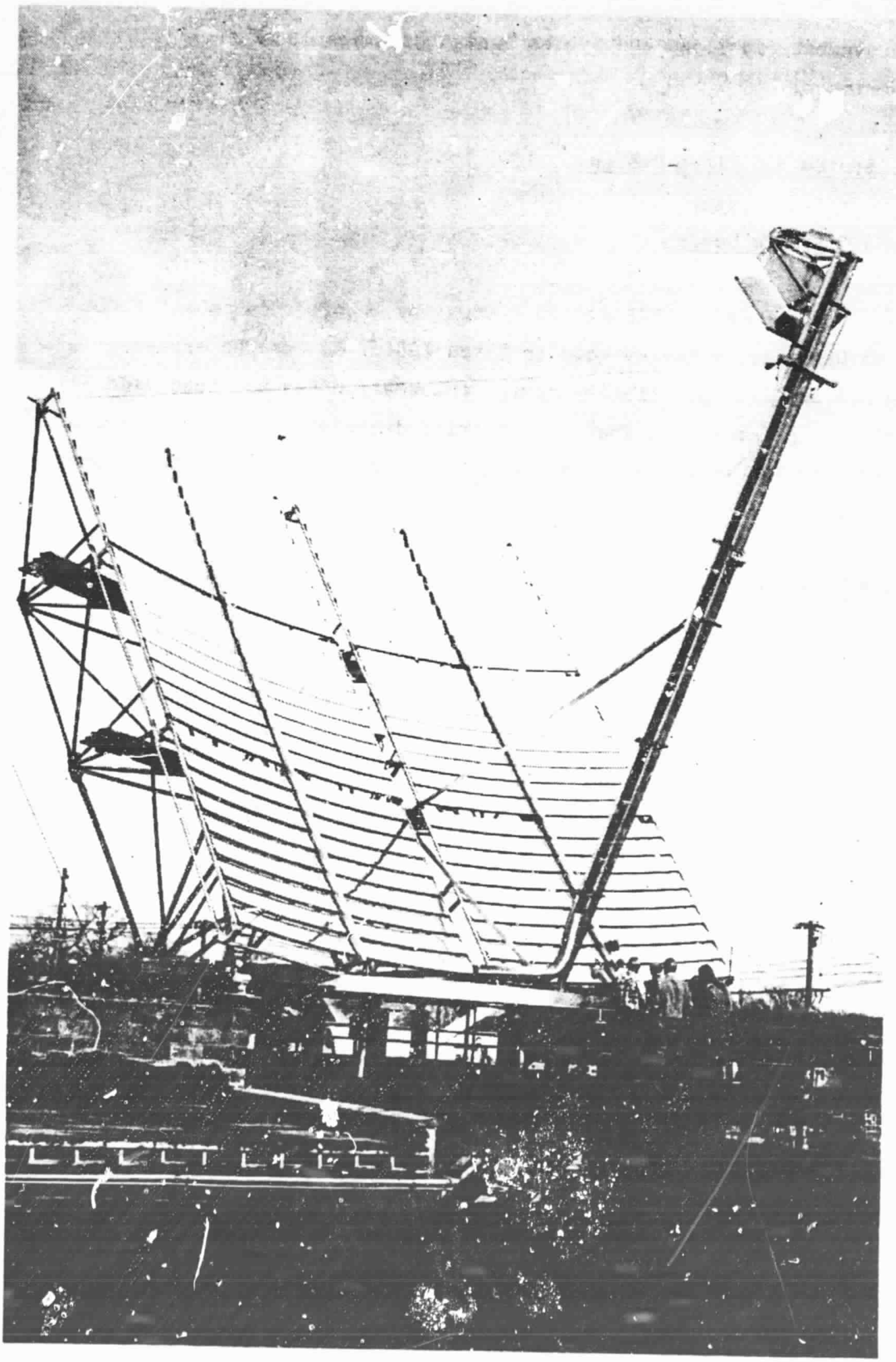
1. System Design

The baseline PKI system design was reported in detail to JPL at an Engineering Review held in March 1981. As per the agreement between PKI and JPL, proprietary design information has not been made available for general distribution. A brief description of the collector as provided by PKI is found as an appendix to this report. A photograph of the installed system is at Figure 12.

Design changes as a result of this experiment can be divided into two categories: Those changes which were made to the prototype system design for or during the experiment, and those which were made as a consequence of the experiment. Changes made for the experiment include, at the system level, those improvements or modifications to the fifth generation prototype which were necessary to the installation of a functioning, industrial plant. They were reported to JPL at the Engineering Review, and implemented in the collectors erected at SNLA and at Capitol Concrete. In addition, as the result of experience at SNLA and Capitol Concrete, field modifications were made as detailed in Sections IIB1 and IIC3 above, in response to problems encountered during check out and operation of the plants, and which required an immediate solution to achieve a functioning plant.

In addition to the design changes implemented for or during the experiment, additional desirable design improvements came to light for implementation in future installations. PKI has provided the

Figure 12: Photograph of PKI Collector



following description of system level design changes to be made as a consequence of this experiment. Some of these have already been used in plants installed at Hill AFB and at Cornell University:

1. Casters

Integration of uplift catches with the wheel assemblies is warranted to eliminate the double installation work. Design modifications of the uplift catch to allow greater flexibility in track tolerences is also warranted.

2. Track Joints

Structural joints which interface with the track may best be redesigned so that they can be bolted to the track instead of site located and welded. Impact of manufacturing tolerances of track and subsequent field assembly must first be investigated.

3. Center Pivot/Fluid Loop

Piping and electrical (instrumentation and control wiring) subassemblies, once standardized, may best be preassembled at the factory. Precut and bent conduit, wire, piping with insulation, etc., should be investigated for standard collector configurations.

4. Standoffs

Enhanced flexibility in three dimensions is required on the standoffs from the face joints of the collector. Site adjustments which require drilling holes should be avoided.

5. Mirrors and Mirror Assemblies

Shipping considerations and handling (both during manufacturing and during installation) requirements of the mirror assemblies make stacking provisions integral with the mirror assembly important. Redesign of the method of mirror capture to allow greater flexibility in mirror dimensions is required. Protective coating of the mirrors themselves may best be done by PKI to insure quality control and enhance delivery.

6. Integrated Azimuth and Elevation Packages

Assemblies built at the factory and tested prior to shipment with limit, control and interface aspects completed will insure expedient installation. Mechanisms with inherently safe operation which will not allow an operator to override functions, which may be detrimental to the collector or safe operation, will be preferred over one the operator must assume decision making responsibility.

7. Receiver Controls

In order to facilitate site engineering, standard failsafe interface packaging will be required for the most common output modes of the collector. A latching receiver overtemperature indicator may be required as a standard feature.

8. Signs and Operator Manual

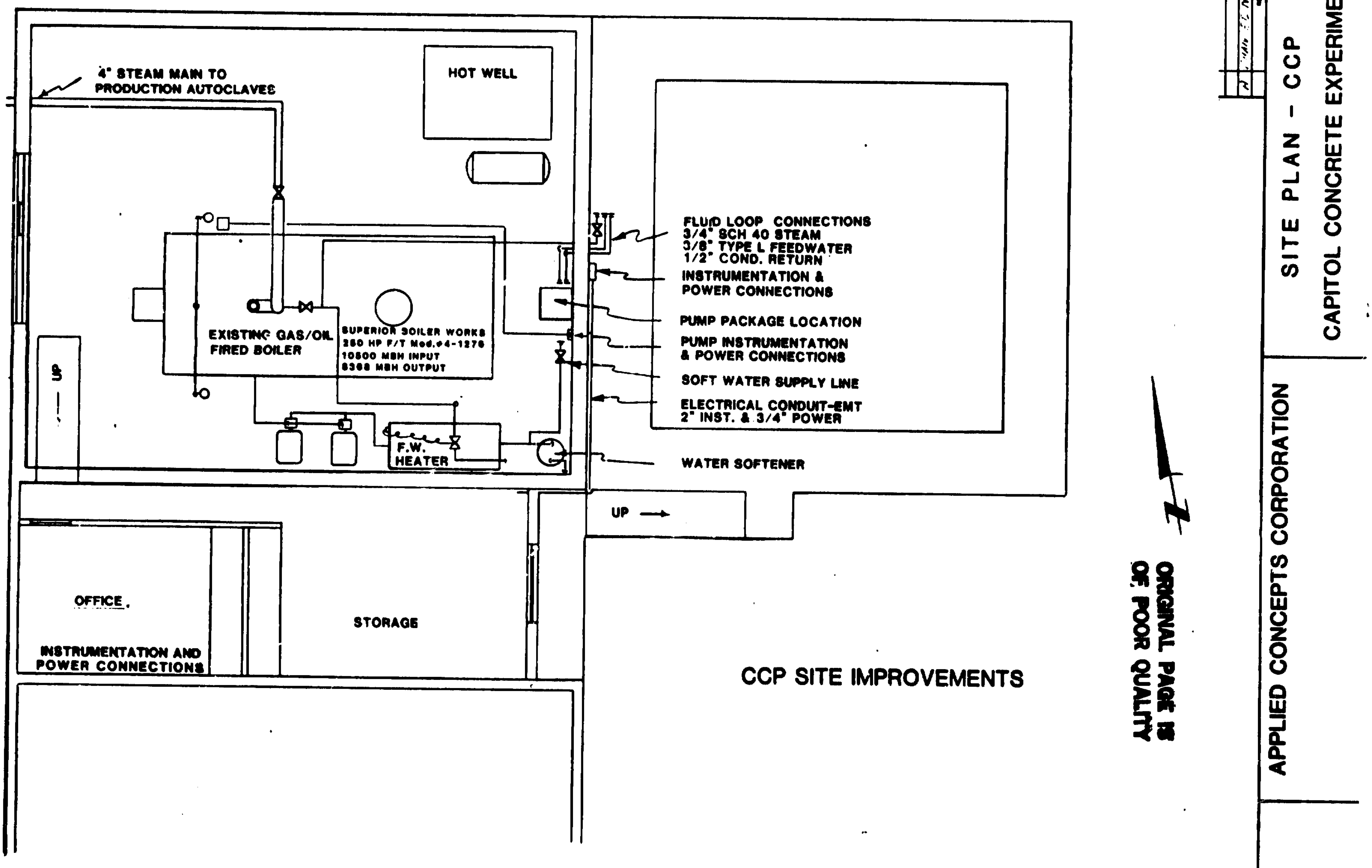
A very simple, picture oriented operator's manual will be required before full mass production of the unit is possible. Greater simplification of operation and the use of permanent signs near devices which need adjustment (shadowbands) or manual control (elevation switches) is warranted.

2. Plant Design

Plant level design was accomplished by Applied Concepts' engineering staff. Preliminary plans in the form of engineering drawings were presented to JPL at the Engineering Review in March 1981. The following figures define the Capitol Concrete plant as built, as of July 1982.

Figure 13, Capitol Concrete Plant (CCP) Site Improvements provides a physical site layout diagram. The large room to the northwest is the existing boiler room where solar plant feedwater input is provided and to which output steam is distributed as per the fluid loop connections on the east side of the room.

Figure 13: Capitol Concrete Plant Site Improvements



The boiler room is at ground level. Steps lead up to the plant manager's office, where solar plant controls, power connection, and the DAS recording package are located. Access to the solar collector is through a storage room, where spare parts are kept, through a door and up a set of metal steps to the roof-level platform which supports the circular track upon which the collector rests.

Figure 14 presents the "as built" fluid loop schematic, defining the energy conversion and distribution flow, and control interfaces. Figure 15 presents the "as built" wiring diagram, detailing the electrical connections for plant control and instrumentation.

Many of the system level design improvements were the result of plant level experience, and were defined with the corroboration of the plant engineer. This is particularly true for the fluid loop and fluid loop/controls interactions which are the primary interface between the collector system and the application, and therefore a principal concern of the plant engineer. Similarly, PKI designer/developers applied their skills and knowledge of the collector design to help solve plant engineering problems.

The system level design changes discussed in sections IIB1, IIC3, and IIA1, are directly the result of plant operations at SNLA and Captiol Concrete, and therefore incorporate certain elements of plant and plant dependent design.

Because each plant installation is unique, it is difficult to identify generic plant design changes. At this level, it is more appropriate to discuss "lessons learned" which can be applied as appropriate to the situation for additional installations. Some general observations include the following:

Figure 14: Fluid Loop Schematic

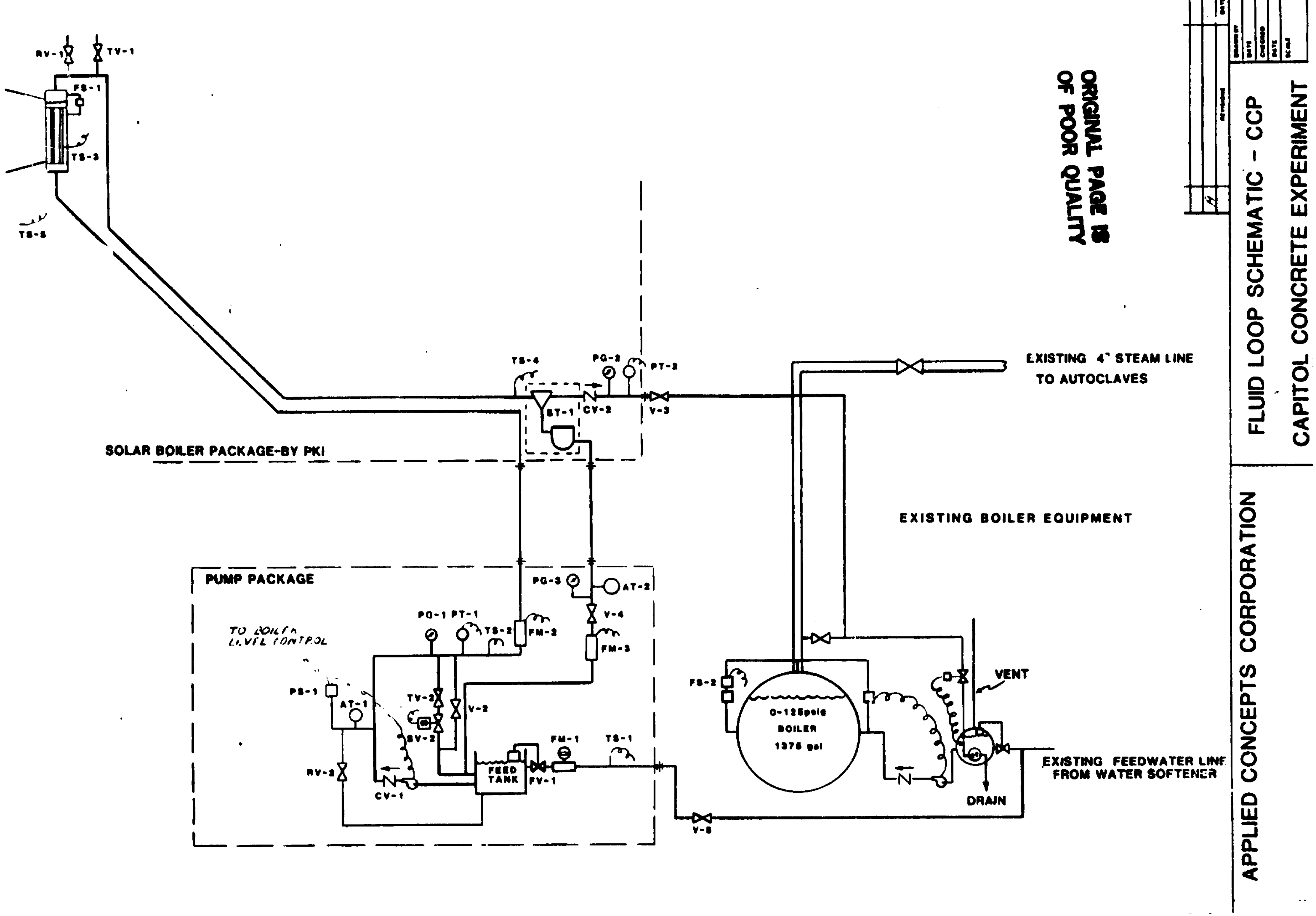
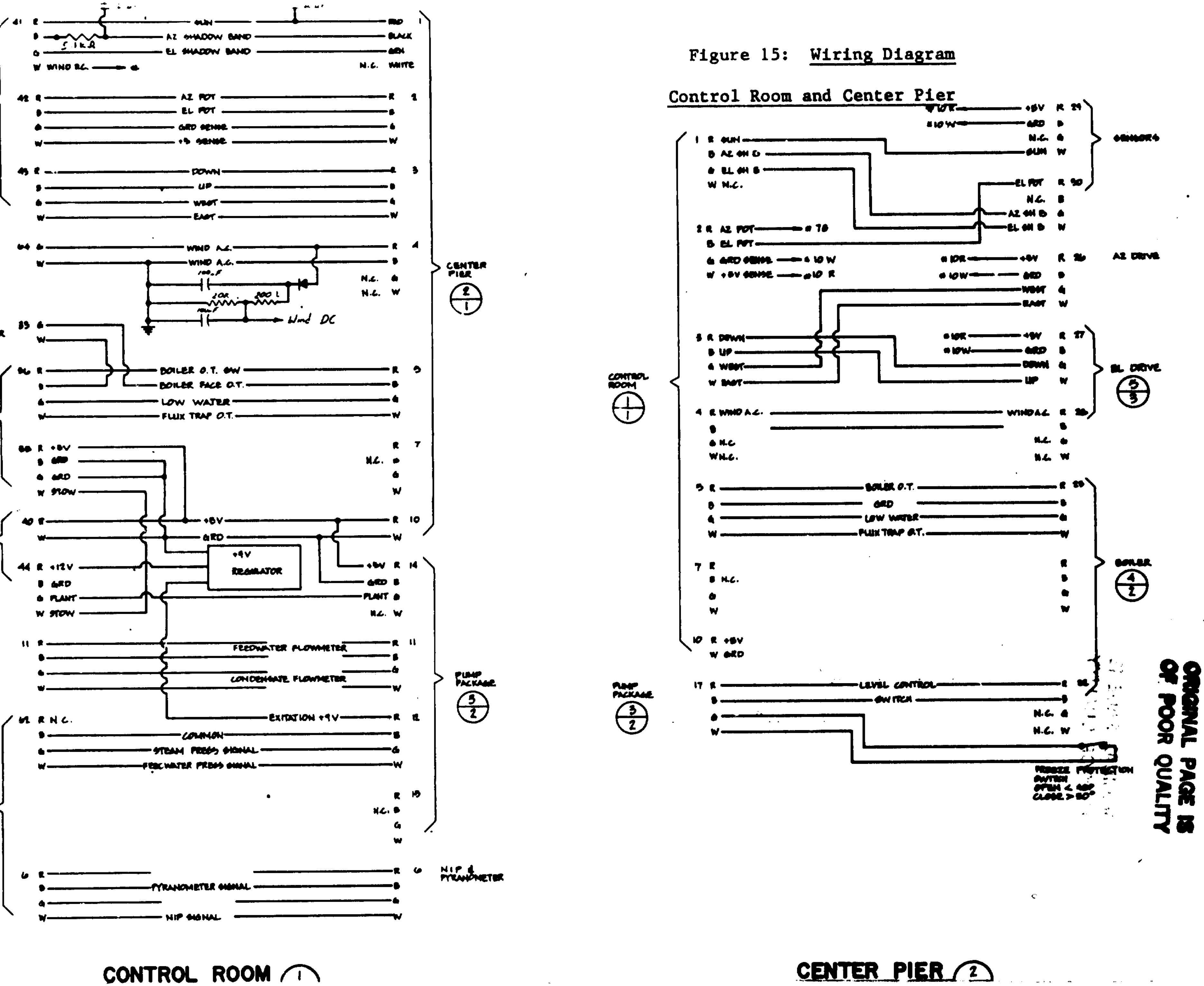


Figure 15: Wiring Diagram

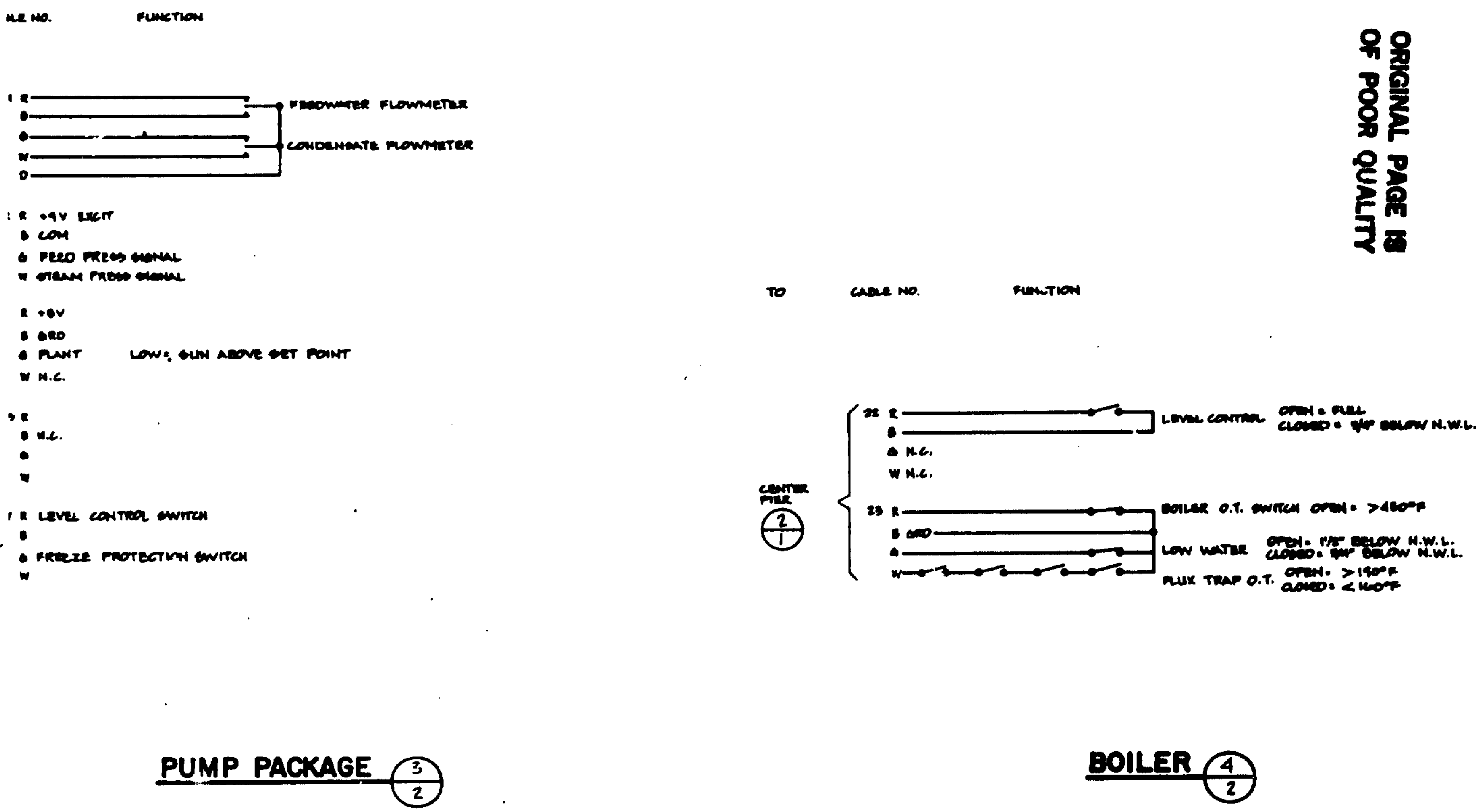
Control Room and Center Pier



WIRING DIAGRAM - AS BUILT
PKI COLLECTOR AT CAPITOL CONCRETE

NONE

Figure 15: (Continued) Wiring Diagram: Pump Package and Boiler



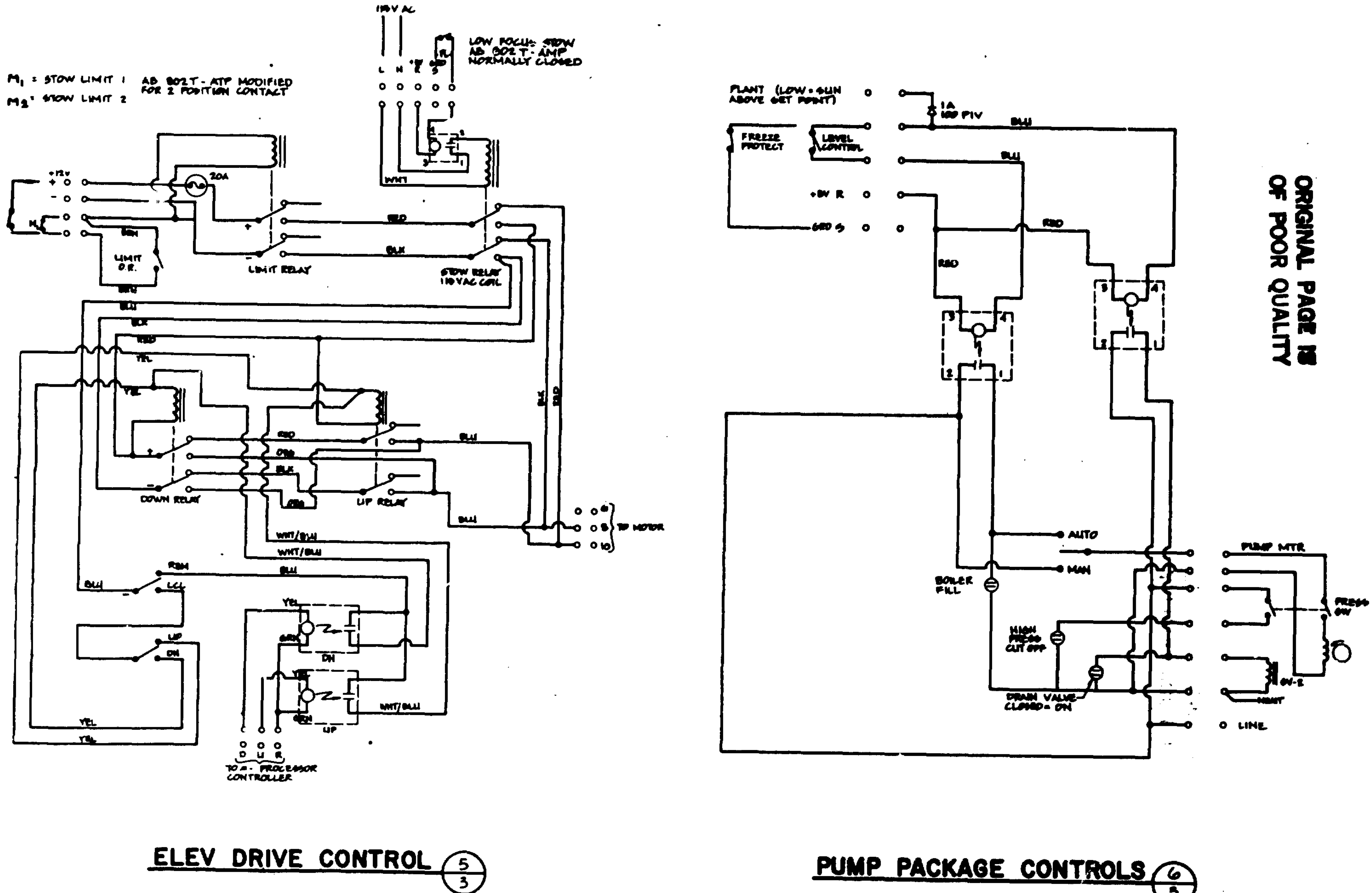
ORIGINAL PAGE IS OF POOR QUALITY

WIRING DIAGRAM - AS BUILT DETAILS

None

K05-1C

Figure 15: (Continued) Wiring Diagram: Elevation Drive and Pump Package Control



ORIGINAL PAGE IS OF POOR QUALITY

WIRING DIAGRAM - AS BUILT

APPLIED CONCEPTS CORPORATION

1. Insolation patterns are critical for installation and check out of a plant. SOLMET insolation data for Topeka indicated that it was a good choice for a representative plant location. In the event, long delays were experienced due to lack of consistent or predictable direct sunlight for check out. Moreover, there were a large number of "clear" days where haziness kept recorded insolation below the 600 watt per square meter threshhold necessary for operating the plant. The need for careful and interpretive check out testing and for extensive travel to the site made for a very long, frustrating, and expensive cycle to make coincident plant readiness for test, the presence of engineering staff, and sufficient sunlight of adequate duration. We advise that, until the collector is more fixed in its design and its check out test more predictable, installations be made close to the engineering staff and/or in areas of highest insolation.

The seasonal variations of azimuth focus with sun elevation angle raise questions about the wisdom of plant installation in Winter. These two factors point to the advisability of developing an artificial or simulative illumination for focus.

2. Although the collector design proved compatible with industrial plant operations, the maintenance and operation of high quality instrumentation systems did not. DASs suitable for industrial plants need to be simple, rugged, and low in their maintenance requirements. The time scale of data collection should also be considered from the point of view of industrial concerns. Precise data gathering should probably be carried out at test sites under laboratory controlled conditions.

3. Elevated platforms are probably not cost effective. Systems should be ground mounted or as close to the application as feasible. The Capitol Concrete platform cost approximately $28,000. This was much more than estimated by our independent designer, and is five to seven times the cost of the SNLA foundation.

4. Extreme care should be taken with design and installation of the drain-down system to ensure proper operation.

5. The installation of solar industrial plants imposes sufficiently unique requirements to warrant the use of an experienced, independent designer to integrate the solar energy plant with production applications.

6. Plant installation contracts involving experimental hardware, should include a contingency line item to avoid administrative delay in negotiating and processing each modification as it becomes evident or necessary.

IV. Conclusions and Recommendations for Additional Experiments and Operating Modes

The Capitol Concrete Experiment has demonstrated that the PKI design for a point focusing solar collector can provide useful thermal energy in the form of 30 - 60 psi saturated steam in an industrial environment. Two months continuous operation at Captiol Concrete, subsequent to a month of verification testing at SNLA, make this conclusion indisputable.

The experience of fabricating, installing, and operating the collectors under this experiment has led to improvements in design which are expected to increase the reliability, operability and safety of the system. To a large extent, these modifications have been field engineered into the Topeka plant. The positive experience with the PKI design together with indicated sunlight to steam conversion efficiencies of 60 to 80% across the range of useable insolation (≥ 0.6 kw/m^2), make the PKI collector an attractive candidate for further development into a commercial product for industrial energy application.

The technology development model referred to in Cnapter I, which underlies the conceptual definition of this Thermal System Engineering Experiment, indicates that a system readiness test or demonstration is the next step subsequent to proof of technical feasibility. System readiness testing incorporates the elements of economic feasibility of system utilization in addition to technical and operational aspects of industrial application.

The results of the Capitol Concrete Experiment have provided evidence that the PKI design is operationally an attractive one. User acceptance has been high. Solar plant characteristics have proved to be compatible with production plant procedures and operations. This is, of course,

a preliminary impression. A final statement must await a longer period of operation. So far the results are attractive.

The experiment has also provided evidence of the basic technical feasibility of the PKI device in that it has operated for two months at Capitol Concrete subsequent to one month's verification testing at SNLA, providing steam at indicated efficiencies of 60 to 80% when direct insolation exceeded 600 watts/m^2.

What this experiment has been unable to provide, and is unlikely to do so before its conclusion in November 1982, is a definition of a performance envelope for even this one site and application. The variables are too many. The operating conditions are uncontrolled and the instrumentation system, already too complex for the environment, is inadequate to completely define all variables.

The most pressing need, therefore, is for a performance evaluation of the PKI design by a scientific/engineering staff in a controlled environment. The principal goal of this testing should be to measure system output as a function of major variables, especially sun elevation angle, position of original focus, and quality of insolation. As a first level of measurement, output should be recorded as solar flux near the focal "point" in three dimensions. As a second level of measurement, total output and efficiency of conversion should be recorded for conversion media at different temperatures and with and without phase change. At a minimum, this should include the generation of steam at low and high temperatures and the heating of water and/or oil at low and high temperatures.

There is reason to believe that the conversion effectiveness of the PKI collector is limited at high temperatures. The inherent lower limit to the area of the focal image which is controlled by the use of flat mirror tiles must be aggravated by the daily and seasonal effects of sun elevation angle on azimuth focus. The instantaneous area of

focal dispersion had never been measured for the PKI design. The evidence that substantial changes in that area occur as a function of sun angle and of original focal point make it mandatory that the technical characterization of the equipment be given a high priority. Only in this way, if now through trial and error, can the true performance boundaries of the design be determined.

It is prerequisite, that the performance envelope of the PKI design be established so that its economic potential can be evaluated. No valid economic forecast can be made until the nature of the market is known. The market cannot be projected until the natural limits of system output are understood. We do know, or suspect, that there are limits to minimum site insolation and quality of insolation for practical application of the design. Limits probably can be defined for the maximum temperature of conversion. There may be limitations as well on the latitude of the site (i.e. to variance in sun elevation angle). Yet the values of these potential limits are still unknown.

The limited experience to date indicates that for those applications when environment and application requirements fall within the PKI design envelope, the system can be an attractive and efficient source of alternative energy. The danger exists that the system will be applied in a situation where one of these factors exceeds the boundaries of the design, and that the subsequent experience will be perceived as a failure of the design, when in fact it was merely a faulty concept. Until the output characteristics of the design are more rigorously understood, this will be a continuing area of ignorance and thus a potential pitfall.

The second need is for much more experience with the PKI system in order to reveal the problems in materials and design which only an extended operation can reveal. In part, this will be accomplished by continued operation of the Capitol Concrete and Hill AFB plants, but more installations would be desireable. Virtually nothing is known about the longevity of the equipment or its sensitivity to different environmental conditions, e.g. humidity, dust, etc.

The more experience can be gained under various operational conditions, the more can be learned about system optimization for desirability and longevity. These factors are critical for economic effectiveness of any energy equipment which substitutes capitol cost for fuel consumption. It is in the interests of the scientific and research communities to keep these early installations running so that knowledge can be gained from that experience. If concentrating solar conversion devices are to be understood, it is also prudent to sponsor additional installations in order to gain varied, additional operating experience. This can be initiated independently of the system characterization tests, which must have first priority, by limiting operating plants to low pressure steam applications in areas of high insolation.

It should be noted that, with the possible exception of the General Electric/Solar Kinetics Inc. Shenandoah dish which has erected many more systems but only one plant, the PKI design is the most developed American, point focussing solar thermal collector. New applications experiments are attractive activities, both to engineers and system developers. The sale of systems is presumably essential to PKI's continued growth or existence. Nonetheless, and based on the results of this experiment to date, we recommend that a thorough system characterization be the first priority in the further development of this potentially attractive solar conversion equipment. In order not to hinder the development of PKI and to promote exploitation of the design, system characterization testing should be begun as soon as possible within available resources.

V. New Technology

No reportable items of new technology have been identified.

APPLIED CONCEPTS CORPORATION

Appendix A

Check Out Test Procedure

PRECEDING PAGE BLANK NOT FILMED

CHECK OUT TEST SUMMARY

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
1.0	Structure		
1.1	Spaceframe		
1.1.1	Mirror Support Assemblies Test: Visual Check Criteria: 1. Secure fastenings 2. No cracks or breaks 3. Mirrors clean 4. Proper mounting in assembly		Check all assemblies.
1.1.2	Tubes and Plates Test: Visual Check Criteria: 1. Coating 2. Integrity 3. Proper location		Check all members.
1.1.3	Joints Test: Visual Check Criteria: 1. Proper number of bolts 2. Properly torqued to 100 ft/lb minimum		Check all joints during assembly.
1.2	Track		
1.2.1	Spaceframe Joints Test: Visual and Manual Checks Criteria: Clean, secure welds		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
1.2.2	Track Welds Test: Visual and Manual Checks Criteria: Clean, secure, smooth bottom surface flat within 1/16 inch		
1.2.3	Track Paint Test: Visual Check Criteria: All surfaces coated.		
1.2.4	Casters Test: Visual Check Criteria: 1. Equal load distribution 2. Minimum of five casters in contact 3. Maximum of 1/4 inch gap		
1.2.5	Doglegs Test: Visual Check Criteria: 1. 3/8 inch radial overlap 2. 1/16 inch minimum clearance to the track web. 3. 1/16 inch minimum and 3/8 inch maximum vertical clearance to bottom flange		
1.3	Boom		
1.3.1	Hinge Test: Move from ground to focus and back		

CHECK OUT TEST SUMMARY

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Criteria: 1. Free movement 2. Proper motor function		
1.3.2	Boom Test: Visual Inspection Criteria: 1. All surfaces coated 2. Visual linearity 3. Midjoint secure		
2.0	Fluid Loop		
2.0.1	Test: Physical Integrity Criteria: Visual check for proper installation		
2.0.2	Test: Hydrostatic Criteria: No pressure decrease for 10 minutes and no leaks		1. Plug RV's manually 2. Pump system up to 150 psig
2.1	Relief Valves		
2.1.1	Test: Allow relief valves to operate normally Criteria: Verify relief and closure at 105 ± 5 psig		
2.2	Pressure Switching		
2.2.1	Test: Verify proper pressure switch operation		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Criteria: Maintain pressure in accumulator of 80-100 psig		
			1. Open manual feed valve V-1 until pump starts
			2. Close valve and note cut in pressure
			3. Note cut out pressure
2.3	Boiler		
2.3.1	Test: Verify Boiler Fill Operation Criteria: ΔFM-2 = 0.3-0.5 gal at a max of 15 sec		
			1. With boom up and system off sun in the normal configuration, open V-2 to drain water from boiler until SV-1 opens.
			2. Close V-2, note FM-2 reading, note time of pump start up.
			3. Note time and FM-2 reading when SV-1 closes.
			4. Verify maintenance of feed tank level within 1".
2.3.2	Test: Verify Drain Down Criteria: Proper drain-down and refill		
			1. Cool temperature switch to 35 degrees F, verify opening of SV-2 and drainage of system.
			2. Allow temperature switch to warm above 45 degrees F, verify SV-2 closure, and refill of boiler.

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
3.0	Controls		
3.0.1	Physical Integrity Test: Visual Check Criteria: Visual Integrity		Check all inputs, leads, shielding and wiring for integrity.
3.1	Sensors		
3.1.1	Elevation Shadowband		
3.1.1.1	Test: Electrical Criteria: Voltage change of ± $10 corresponds to image change of ± 6 inches.		
3.1.1.2	Test: Alignment Criteria: Shadowband in position to hold image in center of receiver within ± 6 inches.		
3.1.2	Azimuth Shadowband		
3.1.2.1	Test: Electrical Criteria: Same as 2.1.1.1		
3.1.2.2	Test: Alignment Criteria: Same as 2.1.1.2		
3.1.3	Sun Intensity		

CHECK OUT TEST SUMMARY

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
3.1.3.1	Test: Electrical Criteria: Voltage change of \$65 ± 5 for direct sun/no direct sun		
3.1.3.2	Test: Visual Alignment Crit ria: Sensor coplanar with collector face ± 5 degrees		Determine visually.
3.1.4	Azimuth Position		
3.1.4.1	Test: Alignment and Electrical Criteria: During rotation of collector 1. S ± 5 degrees corresponds to \$80 ± \$05		
	2. E ± 5 degrees corresponds to \$40 ± \$10		
	3. W ± 5 degrees corresponds to \$CO ± \$10		Runs simultaneously with 3.2.2, 3.4.1 and 4.2.3.
3.1.5	Elevation Pot Test: Alignment and Electrical Criteria: During mirror assembly rotation 1. Mechanical stow limit corresponds to \$FO ± \$05		
	2. Rainwash corresponds to \$BO - \$05		Runs simultaneously with 3.2.1 and 4.1.6
3.1.6	Wind Sensor		

ORIGINAL PAGE IS OF POOR QUALITY

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Test: Electrical Criteria: 30 mph ± 3 corresponds to $45 ± $05		
3.2	Limit Switches		
3.2.1	Elevation Test: Electrical Criteria: 1. Activation of high switch shuts off motor. 2. Activation of low switch shuts off motor and then reverses it to achieve stow position 3. Check location of limits. 4. Manual reset required to reactivate		ORIGINAL PAGE IS OF POOR QUALITY Concurrent with 3.4.3 and 4.1.6
3.2.2	Azimuth Test: Electrical Criteria: 1. Activation of either switch deactivates azimuth drive 2. Check location of limits 3. Manual reset required		Simultaneous with 3.1.4, 3.4.1 and 4.2.3.0.
3.3.0	Safety Systems		
3.3.1	Boiler Over Temperature		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Test: Electrical Criteria: Emergency stow activated if boiler temperature exceeds 400 degrees F.		To be demonstrated.
3.3.2	Low Focus Test: Electrical Criteria: 1. Emergency stow activated when sensor exposed 2. Check location of sensor		To be demonstrated.
3.3.3	Loss of Power Test: Electrical Criteria: Loss of power activates emergency stow		To be demonstrated.
3.4	Microprocessor		
3.4.1	Test: Azimuth Tracking Without Sun Criteria: With shadowband and sunout sensors covered, determine that collector tracks from memory.		Concurrent with 3.1.4, 3.2.2 and 4.2.3.
3.4.2	Test: Azimuth Tracking With Sun Criteria: Image transverses from one side of boiler to other		Concurrent with 3.1.4, 3.2.2 and 4.2.3.

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
3.4.3	Test: Evaluation Tracking With Sun Criteria: Image transverses from top to bottom of boiler		Concurrent with 2.1.5, 3.2.1 and 4.1.6
3.4.4	Test: Rainwash Mode Criteria: Elevation drive to rainwash position with manual activation		
3.4.5	Test: Return to Sunrise Criteria: Return to azimuth position corresponding to set sunrise position		Set clock time in micro to activate this function.
3.4.6	Test: Micro Status Outputs and Modes Criteria: Check LED's		Correlate with modes during control testing
4.0	Drives		
4.1	Elevation Drive		
4.1.1	Drive Train Test: Visual and manual checks Criteria: 1. No obstructions 2. All linkages secure		
4.1.2	Motor Test: Visual Check		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Criteria: 1. Secure mounting 2. Electrical connections 3. Proper lubrication		
4.1.3	Battery		
4.1.3.1	Test: Visual Check Criteria: 1. Secure mounting 2. Electrical connections 3. Fluid level		
4.1.3.2	Test: Charge Criteria: Proper Change		
4.1.4	Lead Screws Test: Linearity Criteria: Visual Linearity		
4.1.5	Alignment Test: Visual Check Criteria: Visual inspection during alignment procedures determines focus (done by mirror assembly, by section and by bank)		Tight focus means all reflected energy tight inside receiver aperture. None is visible on receiver housing or boom, by visual inspection.
4.1.6	Electromechanical		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Test: Performance Criteria: Cycle through stow and focus positions twice without problems. Elevation speed approximately 12 minutes from focus to stow		Utilize local controls at pedestal base. Concurrent with 3.1.5, 3.2.1, and 4.4.3.
4.2	Azimuth Drive		
4.2.1	Roller Chain/Sprocket Test: Visual and Manual Criteria: 1. Proper tension		
	2. Proper lubrication		
	3. Proper position		
4.2.2	Motor Test: Visual Check Criteria: 1. Secure mounting		
	2. Electrical connections		
	3. Proper lubrication		
4.2.3	Electromechanical Test: Performance Criteria: Cycle through complete range once without problems		
			1. Concurrent with 2.1.4, 2.4.1, and 3.4.2
			2. Slew rate - 3.2 hr/rev

ORIGINAL PAGE IS OF POOR QUALITY

CHECK OUT TEST SUMMARY

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
5.0	Instrumentation		
5.1	Thermocouples Test: Electrical Criteria: Successful operation with datalogger		Check disk storage concurrently throughout instrumentation checkout
5.2	Wattmeter Test: Electrical Criteria: Same as 4.1		
5.3	Pressure Sensors Test: Electrical Criteria: Same as 4.1		Concurrent with fluid loop testing
5.4	Flow Sensors Test: Electrical Criteria: Same as 4.1		Same as 4.3
5.5	Wind Sensors Test: Electrical Criteria: Same as 4.1		Concurrent with azimuth drive testing

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
5.6	NIP/pyranometer Test: Electrical Criteria: Same as 4.1		Concurrent with sun level testing.
5.7	Disc Test: Visual Criteria: Compare contents of disc with data tape made during above testing		Can be done off-line.
6.0	General Check-out Test: System Level Test		1. Initiate sun acquisition
			2. Verify active tracking initiated
			3. Check outputs
			4. Verify operation of steam trap and CV-2
			5. Feedwater pump
			6. Verify control system monitoring of fluid loop and drive conditions
			7. Initiate stow
			8. Verify steam response
			9. Verify that CV-2 closes and that TV-1 opens.
6.1	Fluid Loop Test: Hydrostatic and Operational		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Criteria: 1. Maintenance of fluid level in boiler 2. No boiler overheat 3. Pump cycling to maintain accumulator pressure 4. Feed water pump cycling approximately every 40 seconds 5. Steam delivered		
6.2	Drives Test: Operational Criteria: Successful sun tracking determined by visual inspection of focus and performance analysis		
6.3	Controls Test: Operational Criteria: Same as 5.2		
7.0	Plant Level Check-out		
7.1	Site Check		
7.1.1	Test: Verify structural integrity of collector mounting Criteria: No breaks, missing hardware, etc.		Visual inspection
7.1.2	Test: Verify clearance for collector operation		

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
	Criteria: No obstructions		1. Visual inspection for obstructions 2. Cycle in Azimuth to limits of operation using manual control
7.1.3	Test: Verify power availability to control, instrumentation and system interface. Criteria: Power available		Check for proper operation of units
7.1.4	Test: Verify proper connection to system interface. Criteria: No discrepancies		1. Visual leak check 2. Visual check for insulation integrity 3. Verify plant steam system status w/ foreman 4. Verify valves V-1, closed verify valves V-3, V-4, and V-5 open. All drain valves closed.
7.2	Operational Tests		
7.2.1	Test: Verify feedwater flow to pump package Criteria: 2 gpm free flow		Check using feed water flowmeter FM-2

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
7.2.2	Test: Operate in normal energy production mode Criteria: Stable operation for one hour		
			1. Turn on instrumentation system
			2. Perform collector start-up procedure--refer to O&M plan
			3. Verify sun acquisition and monitor receiver temperature
			4. Allow receiver temp to stabilize for 15 minutes.
7.2.3	Test: Verify system shutdown for loss of feedwater supply Criteria: Normal shutdown and recovery		
			1. Disable pump
			2. Monitor receiver temperature, initiate emergency stow if temperature exceeds 450° F.
			3. Verify collector stow
			4. Enable pump and verify boiler fill
			5. Reset controller
			6. Verify proper operation
			7. Allow receiver temperature to stabilize for 15 minutes
7.2.4	Test: Verify high wind stow Criteria: Normal shut down and recovery		
			1. Lower wind stow set point $0026
			2. Verify wind stow flag & machine response
			3. Reset set point

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
			4. Clear flags & reset controller $0076 DA 00
			5. Verify proper operation
7.2.5	Test: Check receiver overtemp. stow Criteria: Proper shutdown and return to stow		
			1. Manually lower set point
			2. Observe results
			3. Reset set point
			4. Reset stow box
7.2.6	Test: Check flux trap over temp Criteria: Proper shutdown		
			1. Switch to local operation
			2. Hold elevation switch down until light hits sensor
			[illegible]set
7.2.7	Test: Verify system shutdown due to loss of power Criteria: Normal shutdown and recovery		
			1. Open system power disconnect
			2. Monitor receiver temperatures
			3. Verify collector stow
			4. Verify high temperature shutoff of drain circuit
			5. Close system power disconnect
			6. Verify proper operation after reset
			7. Perform shutdown procedure-refer to O&M plan
			8. Visual check for leaks, damage, etc.

Test or Procedure	Component Test Criteria	Date and Time Accomplished	Remarks
7.2.8	Test: Verify power instrumentation system operation during temporary power failures Criteria: Normal shutdown and recovery		
			1. Open instrumentation system power disconnect
			2. Verify proper system operation & data retention
			3. Restore system power
			4. Verify system operation
			5. Turn off instrumentation system
7.2.9	Test: Verify Rainwash Criteria: Normal rainwash and return to stow		
			1. Activate rainwash switch
			2. Return to normal
7.3	Supervised Performance		
7.3.1	Test: 48 hour supervised operation Criteria: 48 hours of operation as designed		Normal operation by plant opersonnel under ACC/PXI supervision.

ORIGINAL PAGE IS OF POOR QUALITY

APPLIED CONCEPTS
CORPORATION

Appendix B

Description of the PKI Collector

Description of The PKI Collector

Design Elements

The PKI collector has three primary subsystems: The Square Dish Concentrator, The Receiver/Fluid Loop, and The Microprocessor. These subsystems are described below:

The Square Dish Concentrator

The Square Dish provides the point-focussing function of the PKI system. It consists of 864 flat, one-foot-square, second-surface, silvered glass mirrors. The mirrors are affixed to rows of identical curved supports positioned in a faceted Fresnel design.

Each mirror assembly within the dish rotates through its center of gravity to provide elevation tracking. Two drag links each serve to interconnect half of the mirror assemblies. Each drag link is moved by a lead screw worm gear drive, which is mechanically connected to the elevation drive motor.

The dish is supported by a lightweight spaceframe structure composed of steel tubing members and steel plate joints. This design distributes all wind and gravity loads to the base supports.

The base of the structure is a circular track, inverted to eliminate problems of dirt and ice build-up. The track rides on wheels mounted on concrete piers and is motor-driven by a simple, reliable sprocket/roller chain assembly. The rotation of the entire collector on its base provides azimuthal tracking.

The Receiver/Fluid Loop

A well-insulated galvanized steel receiver is mounted on a boom at the focal point area of the square disk concentrator. A variety

of receivers appropriate for specific applications have been tested, including monotube and parallel tube configurations.

The Microprocessor

A microprocessor-based package provides automatic two-axis tracking and operational control. Shadowbands mounted on the disk are the basis for active tracking during sunny periods. A software program provides azimuthal tracking during cloudy periods so that collection can begin immediately upon reappearance of the sun.

This feature permits the system to begin collection of energy after an extended cloudy period within 10 minutes of detection of a threshold insolation level. An added advantage is the reduction in parasitic losses, since a large motor is not required in order to "catch up" to the sun position.

The control package also includes a real time, clock, digital display, and an integral digital voltmeter.

Automation and Safety Features

One key feature of the PKI collector is its ability to operate in an unattended mode. This is a reflection of the safety features built into the system, the microprocessor control and overall system reliability. The collector is protected against significant damage from any system malfunction or dangerous environmental conditions.

Automatic shut-down conditions include boiler overheating, low feedwater pressure, high winds, user-initiated manual stow, controller failure, AC power loss, low focus, and activation of the low limit switch on the elevation drive.

Although all control functions are automatic and do not require a human operator, periodic inspection is naturally required for maintenance and to resolve shutdowns.

Reliability and Ease of Installation

Reliability has been enhanced through recent design modifications that have either reduced the number of parts or provided for additional standardization. Other refinements have been made to enhance ease of installation and maintenance.

Platforms have been incorporated into the space frame supporting structure to allow safe and easy installation of mirror assemblies and the elevation drive package. The drag link assemblies are located behind the face of the collector, allowing ready access from the working platforms. An electric winch is incorporated into the design to permit easy raising and lowering of the boom for servicing the receiver.

(A review of the PKI technology is given in Applied Concepts Corporation's "Verification Testing of the PKI Collector at Sandia National Laboratories, Albuquerque, New Mexico and JPL's "The Solar Thermal Report" Vol 3, Nuumber 2, February/March 1982.)